COMPUTER VISION TECHNIQUES
IN
SEAFOOD QUALITY CONTROL

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by

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Under the Guidance of

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This Thesis is dedicated to :

The Lord Almighty

&

My beloved parents, wife and son

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CERTIFICATE

This is to certify that the thesis entitled **"Computer vision techniques in seafood quality control"** is an authentic record of research work carried out by **Krishnakumar.S** under my supervision and guidance in the Dept. of Marine Biology, School of Ocean Science and Technology, Cochin University of Science & Technology in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in Marine Biology and no part thereof has been presented before for the award of any other degree, diploma or associateship in any University.

Prof. Dr. N. RAVINDRANATHA MENON

Kochi – 16
September,2009

DECLARATION

I hereby do declare that the thesis entitled **"COMPUTER VISION TECHNIQUES IN SEAFOOD QUALITY CONTROL"** is a genuine record of research work done by me under the supervision and guidance of **Prof. Dr. N. Ravindranatha Menon**, Hon.Director and Emeritus Professor, Centre for Integrated Management of Coastal Zones, Dept. of Marine Biology, School of Marine Sciences, Cochin University of Science &Technology, Cochin for the degree of **Doctor of Philosophy** in Marine Biology and that no part thereof has been presented before for the award of any other degree in any University.

Kochi – 16,
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Preface

Digital cameras working as sensors are versatile and have many applications in food processing. Quality management programmes in food processing industries call for constant vigil to safeguard product quality. Value added products have to be prepared under strict quality norms, complying with stringent standards for size grades, shape characteristics and absence of surface defects. Digital cameras have proven themselves to be better than the human eye in detecting defects or for that matter even quality attributes.

Captured images have to be analysed to get meaningful interpretations. For this specialised and highly versatile softwares are needed. Images are processed first through convolutions and image enhancements before they are subjected to image analysis. Appropriate algorithms have to be developed too. Defect detection, morphometric measurements, edge analysis, shape characteristics etc. could lead to corrective actions during production. The present work was envisaged at establishing the accuracy of digital image analysis in qualitative and quantitative measurements, size grade determinations, size and shape conformance, as well as bacteriological counts and measurements useful in quality assurance. It is hoped that this work would provide future workers sufficient information to devote their attention towards digital imagery and image analysis in quality management of seafood processing. This work when published would provide authentic and dependable literature for future research in the area.

1. INTRODUCTION

Chapter. 1 *Introduction*

Extension of shelf life of seafoods is not the only concern of the seafood exporter, ensuring high quality of the product is top priority too. Seafood is an expensive commodity, particularly due to the demand for it in the developed parts of the world. This has contributed significantly towards the foreign exchange earnings of many developing nations. However, the developing parts of the world are still in the process of improving their infrastructure as well as upgrading their technologies.

Quality control systems the world over, have been for decades, following the process of end product inspection. Lately the emphasis has shifted to quality assurance where the responsibility for ensuring the quality of any product is vested with the manufacturer rather than the regulators. Quality assurance programmes like the HACCP are being widely adopted in seafood export processing units across the world. Such a shift calls for inspection of food quality during production in various stages of the production line. This means inspection of the process as well as the product, requiring very strict monitoring procedures throughout production, right from the stage of harvest.

Human resource called for in such quality assurance programmes can be voluminous while the type of work involved in each one of these 'monitoring stages' or 'control points' is routine and mundane. In such situations both human error and negligence can creep in leading to 'misses' in action-taken procedures. In this context computer vision aided quality assurance programmes have a significant contribution to make. Such quality assurance programmes already exist in the manufacture of engineering goods and precision equipment, where this has further led to the development of robotics in 'accept'/'reject' situations. Robotics also shows promise in the food processing industry, even though records of its application in the seafood sector is lacking (Clark, 1990). Some of the most creative applications in this field will come with the integration of sensing devices connected to computers capable of image analysis and in turn being able to control robotic manipulators. This would permit the removal of meat from bones, separation of fat from lean meat, placement of objects in trays and the adaptation to variable conditions. However, sensing devices and algorithms need to be developed for food application. The main obstacles in this field being the relatively high speed and high volumes of production in the food industry and also the wet and humid atmosphere in food plants as compared to other types of industries. The justification for computer vision lies in the fact that quality assurance programmes call for highly routine and monotonous checking or monitoring processes where human "misses" are highly likely. Success of the computer vision programmes can pave the way for further research and development in areas like image analysis for the food industry and its application in robotics.

Studies on the application of image analysis in sensorics have been deliberately avoided here because they can become quite complicated since the odours of spoilage develop rather early and the visible attributes manifest clear signs of spoilage much later only. Such a study will become meaningful only if an 'artificial nose' is used alongside. Studies have been initiated elsewhere in this direction, however, it does not come within the purview of the present study. The use of a computer based image processing / image analysis quality assurance programme has its limitations in its application. Due to this specificity, application bands should be carefully chosen after deliberating the possibilities. Certain specific areas have been chosen for the current study.

The process of quality evaluation by computer vision based techniques and comparison of the accuracy of such methods in relation to conventional methods could face rough weather since the two methods may be totally independent of each other in style and principle. A certain degree of specificity is hence called for here. In certain selective areas alone computer vision and image analysis become applicable. In the current study a few such selective realms and specific quality related tests and measurements have been chosen deliberately with this fact in view.

Studies on quality assurance may involve monitoring right from the raw material stage to the finished product. Raw material quality control involves sorting and size grading situations since the final price of the product is determined to a great extent by size grades. One or two specific situations in size grading where image analysis is applicable have been evaluated. All quality evaluation needs during production or in the evaluation of the final product cannot be met by image analysis. However, there are certain areas where image analysis would be equally good if not better in assessing the quality of a finished product. Quality control studies also involve microbiological evaluations. Certain specific needs can be very successfully met with computer vision and subsequent image analysis. Image analysis in morphometric measurements of fish and prawns, the application of image analysis in quality checks of seafood products like cutlets and their ingredients such as coating materials, techniques of image analysis in quality related bacteriology applications as well as the use of image analysis in mathematical modelling in seafood process control have been tried out here.

Morphometric measurements are very important in biological studies. The length-weight relationship is one of the standard methods yielding authentic biological information, providing a means for calculating weight from length, to convert logarithmic growth rates into weight, to indicate taxonomic differences and events in life history such as metamorphosis and onset of maturity. Morphometrics deals with the statistical study of measurable characteristics such as total length, standard length, fork length, body depth, head length, pre-opercular length, pre-dorsal length, post- opercular length and also the length of fins, including the first dorsal, the second dorsal, the pre-anal, and the upper and lower lobes of the caudal. The measurements are generally made sex-wise over a wide size range of fresh fish, using fine draftsman dividers, and measuring board and recorded to the nearest 0.5 mm or 1 mm (Venkataramanujam and Ramanathan, 1994). This existing conventional system described here requires the fish to be measured immediately then and there at the site. In this context the image analysis technique plays an undeniably important role. The fish can be photographed digitally, the image can be stored in the camera or a computer for any period of time and leisurely the morphometrics could be measured at one's own convenience. Fish on the conveyor en route to the filleting machine or de-header or de-gutter can also be measured. This facilitates the seafood processor to set his de-heading machine or his gutting machine to the standard size of the fish or prawn being processed, so that processing can proceed smoothly without any problem. Quality checks with regard to prepared / ready to cook / ready to eat products may have three or four dimensions to it. Apart from the routine, time consuming lengthy chemical, biological and sensory tests that could be done on finished products, an important series of tests that are generally carried out on such products is the routine and continuous monitoring of the uniformity of shape, edge characteristics, as well as dimensions like the length, width, diameter, height or thickness of the food item. In the food factories where HACCP system is adopted, the former types of tests viz. the chemical, biological or sensory ones are few and far between as compared to the monitoring of dimensions, shape or edge characteristics which forms a constant/continuous quality evaluation programme. Imaging the products digitally and applying image analysis to study their quality characteristics have been not only initiated, but have come to stay. Both virtual and real scale measurements are possible by the image analysis route. In microbiological studies, colony counting is a common feature. The image analysis route can carry out automatic colony counting. Besides, it may become necessary in certain specific situations to measure the diameter of bacterial colonies, particularly in connection with qualitative rather than quantitative studies on colony characteristics and species related experiments. Studies on antibiotic and disinfectant activities through the Kirby-Bauer antibiotic susceptibility test route involves the development of inhibition zones and the measurement of the diameter of such halos as a direct indicator of antibiotic activity or antibiotic strength or both. The measurement of the diameter of the clear zone is done the conventional way by using a ruler. Here again the image analysis route has tremendous potential. The plates showing the zones of inhibition could be imaged digitally and the diameter of the clear zone measured using the image analysis software. Prawn size grades are weight related. However, weight does have a relatively close and highly linear relationship with length or size. Size can be defined in terms of diameter of the heat curled prawn. The application of image analysis in diameter measurement and the involvement of this diameter in weight computation through mathematical models could provide a significant impetus to the prawn processing and exporting industry.

Conventional and existing methods of quality checks in such specific areas have been compared with the computer vision and image analysis route of quality measurements in order to establish the efficiency and dependability of the computer vision techniques. The study assumes importance in the context of wide scale mechanisation and computerisation in the food industry with a view to avoiding or minimising handling of food products by workers or quality evaluators. Besides, an image analysis route also ensures that the quality evaluations are absolutely non-destructive. The industry is in need of such non-destructive as well as quick quality evaluation techniques, particularly in the context of HACCP or other similar quality management programmes where the lengthy, time consuming tests are to be made few and far between. The present study is a step in that direction.

2. REVIEW OF LITERATURE

The principles of machine vision and its application involves visual inspection of food which is a frequent requirement of process control and quality assurance in the food industry. The inspection may be qualitative where the job is mainly looking for defects in shape, size or surface appearance or it can be quantitative requiring actual measurement of the food product. The qualitative aspects involve measurement of surface feature appearances such as detection of burned spots on baked products like bread or cakes or pastries, detection of incomplete coatings such chocolate, caramel or any other dressings on candy bars, incomplete or crumbled or sloughed off battering material or breading material on cutlets and other breaded products, detection of the number and count of pepperoni slices on pizzas, detecting bruises on fresh vegetables and fruits, detection of trimming defects on meat, meat products, fish and fish products etcetera.

Monitoring the placement of icing on cookies, its content, position etc by computer vision methods and the detection of burned spots on cookies and crackers were done by Gagliardi and Sullivan (1983). Hudson (1984) had explained his studies on detection of holes in pizza crusts through the computer vision route. The inspection of seal integrity was a good example of studies using machine vision. Vision techniques to control the slicing of bacon was also studied by the same authors (Gagliardi *et al.*, 1984). As a part of quality inspection for the presence of stones in nuts Hudson (1984) explained how visual inspection could very effectively detect the stones. Candy bars are generally subjected to very intensive inspection for defects in coatings. Since candy bars are produced on a large scale, machine vision could help to a great extent. The shape and size of pizza crusts need continuous monitoring. He had explained a computer vision based method of monitoring the same. Detection of missing components in a multi component package using vision techniques was also standardized by him. Vision technique studies were made by Gerber *et al.* (1985) to detect bones in meat and poultry; and Rehkugler and Throop (1985) to detect bruises in fresh fruits and vegetables. The identification of fish species using machine vision had been tried out (Anonymous,1986). Kanegif (1987) had also reported a machine vision technique to detect bruises in fresh fruits and vegetables. Another interesting study was the vision technique applied by Babbit (1988) to identify poultry parts. The detection of physical damage on corn and soyabeans were another set of studies carried out, standardized by Gunasekharan *et al.* (1988). Most of these applications were relatively straightforward, using the simplest of vision algorithms available to the system programmers. The use of simple algorithms was often necessary in the food industry because of the extremely high inspection rates required.

The **biological properties** related to vision techniques involve the optical spectra of fish flesh. Hauksson (1991) had discussed in detail parasitic nematodes in marine fish and solutions to the nematode problem. In his discussion on nematodes in fish processing , he had described the problems of nematode migration in dead fish, the distribution of nematodes in fish fillets and the efficiency of candling techniques in detecting nematodes. Bengoetxea (1991) in his discussion on optical properties of classes of fishes had explained that the skin, scales and flesh were important parts with regard to optical properties. Mucous and scales were shiny objects and there was also considerable variation between the optical properties of the flesh of demersal white fish and fast swimming pelagic fishes. The difference in optical properties of the flesh of fresh and frozen fish had also been discussed. Petursson (1991) in his discussion on optical spectra of fish flesh and quality defects in fish under a wide range of vision application studies covering biological and optical properties, had stated that research on detection of cod worms was what initiated most of the studies on the 'water window'. He had also described optical absorption, scattering and diffuse reflectance. The effects of 'lamp-fillet-camera geometry', fluorescence, laser scanning, diffuse transmission and diffuse reflectance had also been discussed. The application of x- rays, CT tomography and fibre optics in quality control machinery was a higher technology in its own right.

Illumination is one of the primary aspects of image acquisition. Bengoetxea (1991) discussing on the lighting set up for automatic detection of ventral skin and blood spots in fillets had explained spatial and temporal distribution of light, the reflecting light, the spectrum of radiation illuminating the object and spectral responses of the optical components. Mcleod (1991) had described in detail illumination techniques for 3D machine vision including 'moire topography' and lidar and structured light. He had dealt with basic principles, coherent and incoherent sources, generating structured light and detection – analysis of light - range calculations, calibration, precision, accuracy, speckle, shadowing etc. Applications of structured lighting in the fish industry had also been discussed. Piironen (1991) had evaluated the illumination requirements and methods for machine vision applications in the fish industry. Backlighting technique, polarized front lighting method, specular dark field illumination and structured lighting have been discussed in detail. Also discussed were omni directional illumination and non-camera based methods. The design of image acquisition required careful analyses of physical properties of objects and materials relevant to the vision task. Selection of illumination and viewing geometries, light source, optics and sensor components etc. were based on results of that analysis.

After capture an image may have to be subjected to **image enhancement.** Research and development in food processing had been revealing a significant shift towards the application of microelectronics to keep up with the advances in the field. Hence the thrust was on image analysis and pattern recognition in quality assurance. Image analysis involved filtering, convolutions and feature extractions. The concept of convolution and the influence of image convolutions in particular had been discussed in a detailed manner by Balland and Brown (1982). The possibility of removing unwanted detail through filtering or enhancing desired detail in the image had also been discussed by them as well as by Diamond and Ganapathy (1982) and Baxes (1984). Filtering had also been studied by others like Suetens and Oosterlinck (1985) and Casansent (1987). Many computational algorithms were available to perform these tasks. All of these algorithms were simple and possible to execute at very high speeds. The most common and simplest filters were simple point transformations called MAPS. These MAPS would look at every pixel in an image and would transform it based on a predefined rule. Thus negation of the image and removal of specific grey levels within the image were typical examples. Saguy *et al.*(1990) had illustrated in detail the effect of these maps . The primary task of feature extraction was often the simple measurement of area, size, shape or location. Smart programming of the image system allowed one to search for any type of feature in the binary image. This involved counting the number of objects or even identifying the type and location of a defect. From this sort of information and a certain number of preset rules a reject / accept decision was to be made for the objects in the image. It is to be noted here that the quantity of data being processed as the image moves from 'image acquisition' through 'feature extraction' would be continuously getting reduced. Thus from the frame storage position of the image acquisition where the image may have 64k bytes of information, filtering and thresholding would reduce it to 8 k bytes and through feature extraction it may get reduced to 256 bytes and ultimately to 1 bit. This successive reduction was absolutely essential when applying machine vision to a real time (high speed) problem, otherwise the imaging system would quickly become bogged down in numerical computations and a practical speed would not possibly be obtained (Saguy *et al.*, 1990).

The word **algorithm** simply means a procedure of rules for achieving a goal or objective. Here the goal or objective is image analysis. In order to achieve the type of analysis of the image required and to arrive at a meaningful interpretation of what the image has to convey, the algorithm plays a vital role. The technique of sorting fish by species involved the use of algorithms that measured the dimensions of various parts of the body and then calculated characteristic shape descriptors (Tayama *et al.*, 1982; Wagner and Walter, 1983). While determining fat content in bacon slices and also on the control of package weight, Gagliardi illustrated an algorithm (Saguy *et al.*,1990).

Machine vision made the automatic estimation of fat-to-lean ratio very straight forward. The technique used area measurement algorithms with a slight twist. A method for the rapid inspection of circular products like biscuits was found to use techniques that included algorithms for the precise location of the centres of circular products and radial intensity histograms to help detailed surface scrutiny (Davies, 1984). Lumetech had produced a machine that could reduce bones and fins to 10-20 % of the usual incidence in fish fillets. Fluorescing bones were detected by a thresholding technique (Huss *et al.*, 1985). Sarker and Wolfe (1985) had described pattern recognition algorithms for orientation of fresh market tomatoes in addition to their classification as well. Saguy *et al.* (1990) explained that the algorithms used to inspect cookies were to simply convert the image to binary black or white, determine the area of the image which was simply the summation of the number of white pixels and to compare the area of any sample cookie to the area of the undamaged/intact standard cookie. This vision algorithm was basic to any vision system. As in the case of the damaged cookie sample, the detection of the bruises on a fruit had a virtually identical algorithm. In the detection of physical dimensions of a food product, a simple algorithm was applicable to the gross estimation of the size of a food product. The gross size only told something about its mass but nothing about the shape of the object. Hence moment calculations may be imperative to compare not only the area but also the major and minor axes lengths, and the orientation and position of the said samples. These data were used not only for size grading but also to locate a food product for further processing operations like robotic manipulations, for instance. The information could then be transmitted to a mechanical system to accomplish size gradings. Dented cans which arose from poor handling of cans in canneries presented a significant problem to the industry. It was desirable to reject dented cans before they were filled or labelled. The study required an algorithm to measure dented area of the cans using area analysis or direct comparison of the test image to a reference image (Saguy *et al.*,1990). Studies on fish product sorting by Arnarson *et al.* (1991) revealed that simple image segmentation procedures were sufficient for the purpose. Minimal non overlapping boxes were drawn around each fish product and the box dimensions were characterised in 2D or 3D. The box limits were then estimated by very high speed line scanning perpendicular to the scan direction. The acceptance rules then used knowledge about sorting criteria and knowledge about the upfront machine to classify the tagged boxes into a few classes. Counting and weight labelling could then be performed simultaneously. In their study on detection of internal defects like bones, worms etc. the key to the solution was the optical defect detection process. Here, only image enhancement through look-up tables and video contrast stretching were resorted to, prior to binarization. The algorithm used for surface defect detection involved region area estimation, after recursive boundary estimation to remove uncertain boundary pixels. Simple region erosion operators by blurring or shrinking, or by morphological filtering were sufficient. During fish sorting classical high speed sorting procedures were applied for moving parts. They involved picture or linescan binarization and exploiting the elongated shape of all fish to generate a fish characterization by a variable number of 2D or 3D slices or to known intervals in space and time. These slices were obtained by sensor scan control in connection with the transport, irrespective of fish orientation. Sorting by species and precise length estimation involved hypothesizing head and tail locations each time an object was detected, and carrying out morphological filtering of selected windows at each extremity. The filter kernels as well as feature combination rules had to be size independent but species dependant. Shape anomalies between male and female offered interesting challenges as did unretracted fins Arnarson *et al.* (1991).

Application of Image analysis in production can help improve quality, reduce wastage and losses. Hu (1962) described visual pattern recognition by using moment invariants as a technique. The application of ultra violet light to detect parasitic nematodes in fish in situ had been studied by Pippy (1970). Schatzki *et al.* (1983) described an x-ray method for image analysis to detect agricultural contraband in passenger luggage which gave an elliptic cross section rather than a rectangular one. Tayama *et al.* (1982) developed a machine to identify fish by species. The technique applied here was the use of shape descriptors. Wagner and Walter (1983) had reported a method of distinguishing between species of fish by measuring the backline of a fish from nose to the tail stalk as a criterion for distinction. Davies (1984) described methods for the rapid inspection of circular products like biscuits. The inspections were to detect a variety of faults such as broken biscuits, overlapping ones, partial coatings of chocolate or jam, surface blemishes and protuberances on their edges etcetera. Halvorsen (1984) reported development of a machine which used a vertical array of LEDs and a corresponding array of photodetectors to detect the image of a fish, the image then was processed and the output given to a gutting machine. Newman (1984 a & b) in his publication on the use of video image analysis for quantitative measurement of visible fat and lean meat had described comparison of VIA, visual assessment and total chemical fat estimation in a commercial environment. 'Glafascan' was a machine developed by the AFRC Food Research Institute at Bristol by Newman (1984 a & b). Devalaeminck (1985) described a robot vision system engineered by High Technology, Holland, which provided a fully automated mushroom harvesting system. The position, height and size of the mushrooms were determined by image analysis and the robot arm was to decide on which mushroom to pick. Lumetech of Carlsberg Research Centre had developed a machine that could reduce bones and fins 10-20% of the usual incidence in fish fillets. UV would cause bones to fluoresce and the bones could be detected by a thresholding technique using water jets. However, this is a surface application and bones inside the fillets may not be detected at all (Huss *et al.*, 1985). Sarker and Wolfe (1985) developed an image analysis and pattern recognition algorithm for orientation of market tomatoes with a below 8% error in classification.

Investigations of Emsholm *et al.* (1987) indicated that it was feasible to develop a mechanical device for automatic inline sorting of fillets with the use of visible light and colour filters. Khodabendehloo *et al.* (1987) of the Food Research Institute in collaboration with Bristol University were involved in fundamental research into the design and use of advanced computer vision and intelligent sensor-guided robots for meat grading, cutting, handling, packaging and cooking. Wagner *et al.* (1987) described a method of species identification of fish similar to the method of Tayama where shape descriptors were used to give a reliability of 90%. Bratas (1988) in his paper on detection of parasites in cod stated that several institutes were in the process of developing machines for this purpose. Different radiations such as ultra violet, visible, infrared, x-ray, ultrasound, laser and scanning laser acoustic microscope (SLAM) were all tried. Hatano *et al.* (1989) reported a work on quality standardisation of fall chum salmon by digital image processor. The aim was to find an objective criterion to analogize the flesh redness from nuptial colouration. The external white distribution rate was significantly correlative to the red and yellow distribution rates. Huse and Skiftesvik (1990) reported a PC aided video based system for behaviour observation of fish larvae and small aquatic invertebrates.

Strachan *et al.* (1990) compared three methods of shape analysis of images to establish the best method to identify fish species. The first method that used the invariant moments technique showed 73.3 per cent sorting reliability. The second method compared the sample shape with a template by doing superimposition of sample over template to determine a mismatch factor. Being computationally intensive it took 1 hour and 30 minutes with a reliability of 63.3 % only. The third method that used shape descriptors was the most reliable showing 90 % reliability. Arnarson *et al.* (1991) in their paper on vision applications in the fishing and fish product industries threw light on the applications in the fish sorting, fish product sorting and detection of internal defect situations. Fish sorting involved grouping by either species or length / weight, the estimation of weight from length, the estimation of growth curve for population determination, tagging dead fish for processing with attributes which could become inputs for processing machines so that machine optimisation was possible etc. Product sorting involved despatching products according to shape, size and weight and carrying out visual quality control for shape and size compliance. Internal defects involved worm detection, detection of bones and bone residues, surface defects in terms of colour defect detection etc. Arnarson *et al.* (1991) also described the optical properties of fish classes including that of skin, scales and flesh. Also mentioned were the sensors, environment, hazards to detection besides the read out speed, the dynamic range, the spectral sensitivity, camera synchronization, the robustness etc. Nielsen *et al.* (1991) while giving an overview of vision opportunities in quality assurance had discussed the future of vision-based quality assurance at sea and in the processing factory, particularly at the products department. Grading and sorting of fish, fish products and other seafood had a future because of its accuracy. There was also scope for identification of species. Vision techniques were also researched for trimming and portioning with sensor-guided robots. Monitoring of critical control points in processing was another application. This was besides the possibilities of inline vision-based quality monitoring from harvest to the final product. The authors had further discussed that predictive methods can be devised for both microbial evaluation and sensorics. They had stated that changes in colour, transparency etc. were indices of quality and could be recorded by cameras. Further research was recommended. Many of the inline methods suggested by them were defect detection techniques. Measurement of fluorescence was also said to hold promise in this area. Defects to fillets and the presence of skin and bone fragments using UV light detection were also discussed. There was also scope for the detection of blood spots and gaping in fillets. The requirement for a sensor based system to be used in line were extensive according to them. In the fish industry the most plausible sensor was one based on vision techniques. According to Nielsen *et al.* (1991) a test system should give a linear relationship with time of storage as it did with temperature. Strachan and Murray (1991) in a review on image analysis in the fish and food industries, cited several studies related to image analysis. At Torry Research Station there are two image analysis systems. While one did species and size grading, the other did morphological and particle analysis. Both systems were using conventional video cameras and imaging technology. The host computers were an IBM PC – compatible and a Sun 3/160 C workstation, respectively. A general purpose pattern recognition machine is CRS WISARD manufactured by CRS Computer Recognition Systems. This was used in collaboration with Brunel University to sort fish by species. Loctronic graders in conjuction with the Essex Electronics Centre were involved in developing a real time true-colour sorting system using image analysis for inspection of fruits, vegetables and other food products. Neptune Dynamics Ltd. manufactures the HDIS Herring Sex Discriminator. The machine could separate mature fresh herring by sex. According to Newbury *et al.* (1994) fish populations could be counted automatically by artificial neural networks. A ninety four per cent success rate on scenes containing up to 100 fishes in a variety of orientations and overlaps was possible. Thiel and Wiltshire (1995) had carried out work on automated detection of cyanobacteria using digital image processing techniques. An accuracy of 90 per cent was reported in distinguishing between Anabaena and Oscillatoria. Thiel and Wiltshire (1995) had also reported an automated object recognition system for blue green algae in water quality measurements. Image segmentation routines were applied. Using shape algorithms (Fourier descriptors, moment invariants) and textural algorithms (cell finding algorithms, statistical measures) features were identified, extracted and fed into a classifier which could correctly predict 155 samples out of a total of 158 using discriminant analysis. Beddow *et al.* (1996) studied the prediction of salmon biomass remotely using a digital stereo imaging technique. A high degree of accuracy was obtained. Beddow and Ross (1996) also reported that biomass of Atlantic salmon was predicted from morphometric lateral measurements. Israeli and Kimmel (1996 and 1998) have used computer vision techniques to monitor the behaviour of hypoxia stressed *Carassius auratus*. The quality of golden delicious apples by colour computer vision was carried out by Leemans *et al.* (1997). The system developed was able to grade correctly up to 94 per cent using three colorimetric parameters R, G, B or H, S, I and up to 91 per cent by using the single canonical variate. Defect detection levels for russet, scab and fungi showed promising results. In 1998 Israeli and Kimmel have reported the use of computer vision in studying behavioural responses of carp (*Cyprinus carpio*) to ammonia stress. Jonsdottir *et al.* (1999) have carried out studies on a PC based rapid sensory evaluation method called the quality index method (QIM). The authors claimed that the method used database in detailed descriptive form with assigned scores and demerit points following the "Torry scale". The method was said to be quick and non destructive. Zion *et al.* (1999) reported a study on sorting fish by computer vision. Three fishes such as Carp, St. Peter's fish and Grey mullet were subjected to imaging based on moment-invariants and geometric considerations (shape of the whole body or shape of the tail , fish length etc). High correlation was found between manual measurements and binary image measurements using image analysis. Zion *et al.* (2000) also reported an in – vivo fish sorting system using computer vision. An image processing algorithm was used based on the method of moment invariants coupled with geometrical considerations. Hockaday *et al.* (2000) had reported an extensive study on investigations into shape characteristics study using focus networks in order to estimate the biomass of *Oreochromis niloticus*. Models estimated total biomass to within one percent. Karplus *et al.* (2003) stated that positive phototactic and rheotactic innate responses of guppies were used to induce them to swim through channels for sorting using computer vision and image analysis. Al Khayat *et al.* (2004) carried out single particle analysis as a new approach to solving the 3d structure of muscle myosin filaments. Two principal methods were used to define the myosin head arrays in filaments in relaxed state, namely modelling from low-angle x ray diffraction data and image processing of electron micrographs of isolated filaments. Careche *et al.* (2004) described a multisensor for fish quality determination. The techniques used for this multisensor approach were based on visible light spectroscopy, electrical properties, image analysis, electronic noses and texture. Combining the outputs of instrumental techniques and calibrating them with sensory scores of Quality Index Method (QIM) for attributes like appearance, smell and texture gave an Artificial Quality Index (AQI) that was as accurate and precise as QIM. Enumeration, measurement and identification of net zooplankton samples using the ZOOSCAN digital imaging system was accomplished by Grosjean *et al.* (2004). The semi automatic identification of taxa with various machine learning methods were described. A new 'discriminant vector forest algorithm', one of the most efficient methods, showed an accuracy of 75 per cent at a speed of 2000 items per second. Kato *et al.* (2004) have developed a computer image processing system for quantifying zebra fish behaviour. Taira *et al.* (2004) applied layered neural networks through image processing data to discriminate between species of fish as a follow up of the author's previous works. A modified particle image velocimetry (PIV) algorithm was applied to serial sections of white muscle of adult zebra fish to determine the 3 D fibre angles. The optical sections of thick muscle sections were taken using confocal microscopy. Three dimensional vector fields showing the orientations were then produced at each plane throughout the body.The surfaces of the myosepta in 3 D were also reconstructed by manual digitisation from the serial sections. Cross correlation based image analysis techniques were then applied to compare with the previously constructed "muscle fibre trajectories" (Tytell, 2004). Chen (2005) reported a study on the cleaning effects of fisheries trays using an image processing system and stated that the method is simpler and costs less time than the conventional method. De Wet *et al.* (2005) worked on computer assisted image analysis as an alternative method to determine body weight and condition of fish with allometric growth. A relationship between body weight, length, depth, image pixel surface count and image pixel periphery count of the same species in a fixed weight range was studied and a goodness of fit of regression equations computed. Friedland *et al.* (2005) had developed an automated egg counting and sizing technique from scanned images using high resolution optical scans of plated oocytes with an imaging software and user defined object classifications to separate oocytes from auxillary material. False negatives or misclassifications were as low as 1 per cent in automated counts. Hanzelova *et al.* (2005) described a morphometric analysis of four species of a cestode (Pseudophyllidea) parasitic on salmonids by both interspecific and intraspecific comparison. Univariate statistics was first used to separate individuals and subsequent multivariate discriminant analysis in order to separate all four species. The comparison that followed provided interesting findings. The characters most suitable for species differentiation were the length of the scolex, the width of the apical disc, the width of the neck and its area, the width of the eggs and the number of testes. Smith and Rumohr (2005) described image techniques like scientific imaging, wide area imaging systems, high resolution systems, carrier platforms, special applications, laboratory imaging and analysis in their. Taira *et al.* (2005) described development and use of a discriminant method for fish species by neural networks with image processing data. In this method, automatic procedure from fish image processing to fish species discrimination was achieved. This experiment was aimed at ways and means of reducing the large number of input data needed for the programme. Automation of image matching, cataloguing and analysis for a photo identification research was described by Adams *et al.* (2006). Matching and cataloguing of images of bottlenose dolphins using a multiple attribute, non metric catalogue sorting algorithm from a database was described here. Al Khayat *et al.* (2006) had followed up their previous report with further work on 3 D structure of relaxed fish muscle myosin filaments by single particle analysis. Relaxed myosin filaments of goldfish muscle were viewed in negative stain by electron microscopy, divided into segments and subjected to three dimensional single particle analysis without imposing helical symmetry. The new density map correlates well with the head conformations analysed in other EM studies and x-ray fibre diffraction data. Dunbrack (2006) conducted in situ measurements of fish body length using perspective based remote stereo video. In situ video image analysis was non destructive. Test samples of pipes and free swimming sharks differed by an average of only 1.6 per cent between image analysis measurement and manual measure. Ernst (2006) reported that an image processing system could be used for filamentous cyanobacteria in environmental water samples. A fast, easy and accurate method to determine cell densities without costly and tedious manual handling was described. Automated image analysis as a tool to quantify the colour and composition of rainbow trout cutlets involved methods to measure quality traits such as fat percentage, flesh colour and the size of morphologically distinguishable subparts of the cutlet, the dorsal fat depot and the red muscle regions. Correlation for manual and automatic image analysis for identification of regions; between area of visible fat, cutlet flesh and chemical fat percentage measured by MIT, showed positive results. PCA loading plots were used to identify subsets of variables from image analysis of special significance (HelgeStien *et al.*, 2006). The effect of pre and post mortem temperature on rigor in Atlantic salmon muscle was measured by four frequently used methods for assessment of rigor. Among them whole fillet contraction (WFC, percentage shrinkage) was done by automatic image analysis (Kiessling *et al.*, 2006). Pigmentation levels and morphometric measurements on formalin preserved specimen of lampreys has been tried (Neave *et al.*, 2006) using digital imaging technique for image acquisition followed by image analysis. Nishimura *et al.* (2006) stated that there was good correlation between the count obtained for marine bacteria applying 'Bioplorer' image analysis technique as compared with counts obtained by EFM (Epiflourescence microscopy) and FCM (Flow cytometry) methods. They used an automatic cell counting system called Bioplorer (BP) with LED illumination for enumeration of marine bacteria. Attempts at determining the most pertinent morphological identification criteria of the larvae of *Pinctada margaratifera* and to differentiate them from three other species viz: *P. maculate*, *Crassostrea cuculata* and *Chama sp.* was done by Paugam *et al.* (2006). The limitations of image analysis in real time field studies was stressed by them. Serdaroglu and Purma (2006) reported studies on rapid techniques to determine the quality of seafood. They have examined various methods and established that for inline processing there is a shift towards rapid physical methods to assess quality and among these image analysis was an important area. Six standard morphometric lengths and 10 areas of pigmentation were analysed. Seven morphometric parameters on the embryonic development of the blue king crab, *Paralithodes platypus* was studied using image analysis by Stevens in 2006 (a and b). A study on the setting of colour data in fish species discrimination using neural networks was reported by Taira *et al.* (2006). An effective setting method of colour data for fish discrimination was effectively achieved.A reduction in the number of colour parameters was also made possible. Torisawa *et al.* (2006) had proposed a technique for calculating bearing and tilt angles of walleye pollock photographed in trawls with digital still picture loggers. Confirmation of the calculated angles and their accuracy was compared with computed angles measured using an image processing software. There was good agreement between both the angle readings obtained. White *et al.* (2006) conducted studies on automated detection of species and measurement of length of fish by computer vision dependant techniques while transporting the fish along a conveyor and passing the fish under a digital camera following fixed algorithms.

The 'Catchmeter' was described here. A moment invariant method was used to differentiate morphological makeup. Length could be measured with a standard deviation of 1.2 mm and species differentiation with up to 99.8 per cent sorting reliability for the seven species studied. High speed processing was possible here according to the authors. Xu *et al.* (2006) had studied behavioural responses of the fresh water fish Tilapia (*Oreochromis niloticus*) to acute fluctuations in dissolved oxygen levels as monitored by computer vision. A new image processing algorithm for quantifying the average swimming speed was achieved as a result of this behavioural studies. Yokota *et al.* (2006) reported a study related to the influence of high pressure water jets on surfaces to remove marine attached organisms. This study compared a pressure sensitive film technique to an image processing method. Imai and Yamamoto (2007) applied an advanced method for measuring body length of landed fish using image analysis. Fork length (FL) measurements were done on fishes inside polystyrene containers by applying correcting functions. Ma Bin *et al.* (2007) have conducted studies on six colour segmentation of multicolour images in the infection studies of *Listeria monocytogenes*. Multiple immunoflourescent staining was a powerful strategy for visualising the spatial and temporal relationship between antigens, cell populations and tissue components in histological sections. Multicolour analysis was accomplished here. Roth *et al.* (2007) reported a study on blood spots on fillet surfaces as a criterion for fillet quality, using mechanical, sensory and computer imaging techniques to evaluate the presence of blood spots. Theodosiou *et al.* (2007) reported a comprehensive review of image processing systems to be effectively used for evaluation of FISH and IHC images, highlighting the great advantages of image processing. A specialised software package was developed and applied by Vasilkov (2007) to estimate the age of marine fish using image analysis. Mathematical methods and algorithms were described. The motility behaviour of fed and starved bacteria of 3 selected strains were compared using image analysis by Yam & Tang (2007). Misimi *et al.* (2008) had described a computer vision based evaluation of pre and post rigor changes in size and shape of Atlantic cod (*Gadus morhua*) and Atlantic Salmon (*Salmo salar*) fillets during rigor mortis and ice storage. The effects of perimortem handling stress on fillets had been discussed.

Most of the work on **modelling** in connection with fish and fisheries has been in the area of stock assessment, growth models like the Von Bertalanffy growth model (VBGM), multi-model inference (MMI) on growth, the process of selection and recruitment to fishable size or legal size, modelling associated with fish behaviour etc. However, currently the spectrum has widened into areas like predictive microbiology, predictive spoilage, multivariate modelling for evaluation of freshness, experimental modelling for validation of environmental conditions for growth and rearing, fish locomotion, economics and modelling as well as modelling for fishing options. A mathematical model for various freezing processes of fish and fish products was reported by Ghraizi *et al.* (1996) at the Institute of Thermophysics of the Odessa State Academy of Refrigeration at Ukraine. Shahidi *et al.* (1997) in their book entitled "Seafood safety, processing and biotechnology" had described the importance of modelling in seafood quality and safety. Dalgaard (1998) had given an introduction on microbial methods and predictive modelling in food quality and standards for fisheries under the topic 'Aquatic products and their 'utilization' in The Proceedings of the final meeting of the Concerted Action on Evaluation of Fish Freshness. A report on 'Modelling of seafood spoilage' in the bulletin of the IIR described empirical models on the freshness of sea foods as well as empirical models on the remaining shelf-life of sea foods (Anon, 2000 a). In an investigation on 'Predictive microbiology applied to chilled food preservation' discussed at the IIR Conference at Quimper in France, themes such as predictive microbiology, modelling of microbial growth as a function of temperature, modelling for growth and survival using other factors, predicting changes in safety and quantity of chilled food products, prediction of microbial behaviour, time-temperature integrators, validity of models and reliability of predictions etcetera had been discussed (Anon, 2000 b). 'Fish heaven' was a spatially explicit, age-structured fish model containing the basic features of standard fish modelling with a number of optional extras designed to test the efficacy of different statistical sampling regimes given various plausible spatial structures of fish stocks (Ball and Constable, 2000). In a paper on modelling fish stocks, Cotter and Buckland (2004) had used the EM algorithm to weight data sets of unknown precision. Lem *et al.* (2004) had reported a study on the economic modelling of fish consumption. Mathematical and conceptual modelling of fish behaviour had been reported by Thiele and Ferno (2004). A model on decision making by fish in a chaotic situation inside the nets had been reported by Kim and Wardle (2005) using the Lorenz chaos equations. An accurate and practical mathematical model derived by them on fish kinematics had been described in detail by Guo and Wang (2005) in the Proceedings of the

International Offshore and Polar Engineering Conference. Ion mobility spectrometry based analysis in food quality assay was done in which fish quality changes during cold storage was modelled by Raatikainen *et al.*(2005). In a study on modelling fish growth, Katsenavakis (2006) reported that model selection uncertainity ought to be taken into account when estimating growth parameters. Sarkar *et al.* (2006) had described the application of the software Matlab version 7.0 to predict the water temperature of a fish rearing tank by numerically solving governing equations of heat losses through conduction, convection, radiation and evaporation. The model was validated and the predicted and experimental values of water temperatures exhibited a correlation co-efficient of r = 0.9 and the root mean square percent deviation of 'e' was equal to 1.67 per cent. Modelling fish numbers for stock assessment based on length-dependent change was the type of work carried out by McGarvey *et al.* (2007). Fish numbers within each cohort were partitioned into length bins called slices. This facilitated partition of the continuous length-at-age distribution, thus differentiating legal from sub-legal fish. The fish numbers varied dynamically with length as well as age in the model population array, thus making it possible to model fish numbers. Katsanevakis and Maravelias (2008) had reported a Multi-Model Inference (MMI) as a better alternative to using the Von Bertalanffy Equation. MMI based on information theory was proposed as a more robust alternative to studying fish growth. Modelling of fish contamination with 90Sr in relation to the Calcium concentration in water had been reported by Kryshev (2008). A set of data on the equilibrium concentration factors of 90Sr in fish in relation to the Calcium concentrations in water was analysed to obtain an empiric relationship between the two.

3. MATERIALS AND METHODS

Any image analysis study would involve three stages. The first stage would consist of the image capture. For this, besides the specimen, the digital camera, illumination and ambience would be important. Such equipment were common to all the tests carried out in the present investigation. The second stage would involve image transfer and storage of the images. This need would have to be actually met by the memory cards and the computers used for the study. These equipment too were common ones for all the experiments in this study. The third stage would involve image analysis requiring an appropriate software. Either a single, common, custom made software or several softwares may be applicable depending on the basic capabilities of the software and the requirement of the programme. In the present study, a common image analyser software was used for all the experiments.

3.1. Digital image acquisition

A Nikon digital camera coolpix 5000 with a resolution of 5 megapixels was used for image capture. The specifications of the camera is given below. There were 6 image options. Full (no icon) 2560x1920 pixels, UXGA

1600 x 1200 pixels, SXGA 1280 x 960 pixels, XGA 1024 x 768 pixels, VGA 640 x 480 pixels and 3 : 2 having 2560 x 1704 pixels. The higher resolutions were used in situations were the objects of study were very small. In other cases only lower resolutions were used for imaging.

3.2. The image recorder

For consistency or uniformity of light intensity in all images taken, the images were captured inside a fibre board box of 36.5 cm height, 27.5cm width and 20.5 cm depth with its inner walls covered with matt finish white paper background, a white cutting board at the base, the box illuminated with a CFL of 8 W, 10 lux brightness and a circular opening at the top through which the camera lens could protrude in. The images were captured with the flash in cancel mode, auto adjustable aperture and fixed shutter speed in macro mode.

3.3. Image transfer, storage and image analysis

A laptop with specifications such as 256MB RAM, 16MB VideoRAM, graphics controller, NVIDIA GE Force 2 graphics card and a IEEE port was used. Photoshop/photostudio/ACDSee were for image enhancement and a custom made image analyser software was used for the image analysis work.

The second computer was a HP desktop model with 512 MB RAM, 3.2 GHz clock speed, 160 GB Sata HDD, 128 MB video RAM with a ATI Radeon X 300 SE PCI Express graphics card and an IEEE port. Here too, for image enhancement there were softwares such as photoshop, photostudio and ACDSee and in addition a custom made image analyser software was used for the specific scientific image analysis work.

3.4. Morphometric measurements

Morphometric measurements were carried out on fish and crustaceans. For this study two species of fish were chosen, the Indian Mackerel, *Rastrelliger kanagurta* and the Indian Oil Sardine, *Sardinella longiceps* and two species of prawn White, *Fenneropenaeus indicus* and Tiger, *Penaeus monodon.*

3.4.1. Morphometric measurements on fish using image analysis

Fishes were collected regularly from the market over a period of one year in small lots of five / ten numbers each. The fishes were then weighed and their weights recorded. In all 288 Mackerels were subjected to the measurements and so also 253 Sardines. The methods described by Venkataramanujam and Ramanathan (1994) was followed in conducting the morphometric measurements manually. The data was recorded regularly for total length (TL), fork length (FL), standard length (SL), body depth (BD), eye diameter (ED), snout (S), post orbital length (POL), head length (HL) and also caudal peduncle height (CPH).Only these nine morphometric readings were recorded.

Each one of these fishes, the 288 mackerels and 253 sardines were placed inside the image recorder for image capture and photographed one by one in JPEG 2560 X 1920 resolution using the digital camera. The captured images were then transferred to the computers for storage and image analysis. The specific image numbers were noted. The image analysis was carried out (Plate I, Plate II) on the respective numbered images using the custom made image analyser software, following the method described by Arnarson (1991). The algorithm followed was:

Image – filter -- calibrate – measure -- spread sheet

3.4.2. Morphometric measurements on prawn using image analysis

Prawns were collected from the market regularly over a period of one year in small lots of 5 or 10 or 15 and subjected to morphometric

PLATE I

Calibration and measurement of nine morphometric lengths on Mackerel (*R.kanagurta*) using image analysis

The morphometric lengths measured were Total Length(TL), Fork Length(FL), Standard Length(SL), Body depth(BD), Eye diameter(ED), Snout Length(S), Post orbital Length(PL), Head Length(HL) and Caudal Peduncle Height(CPH).

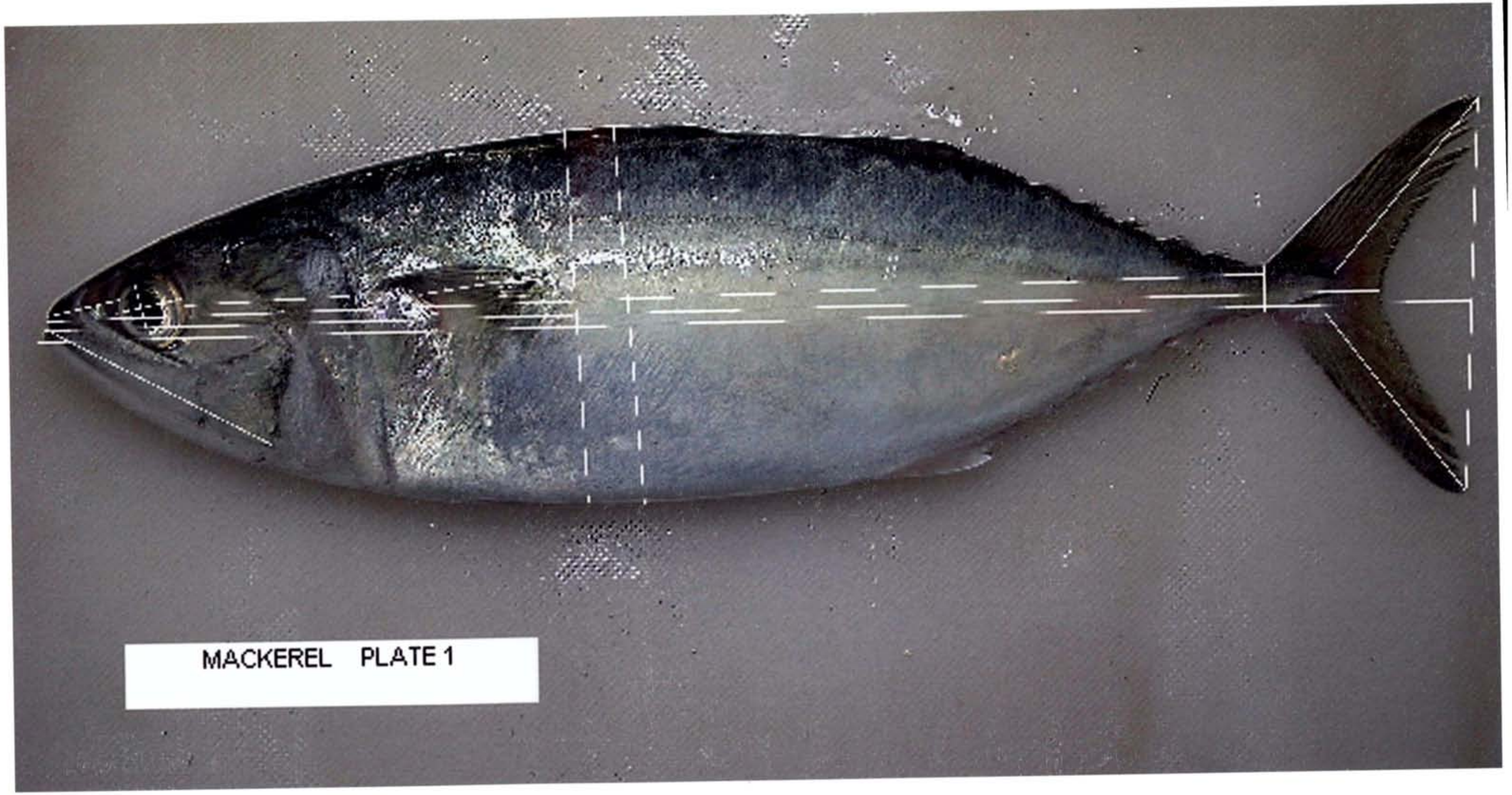
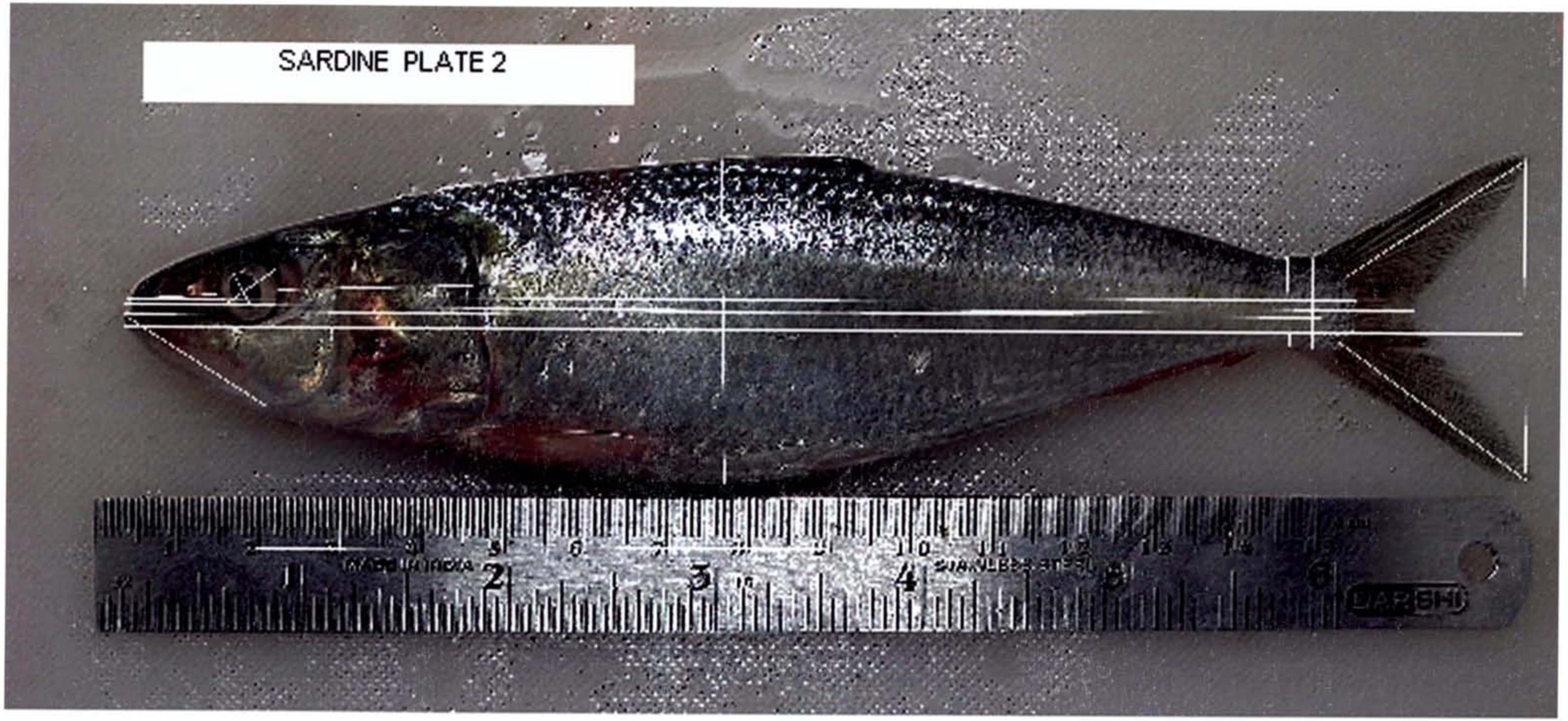

MACKEREL PLATE 1

PLATE II

Calibration and measurement of nine morphometric lengths on Sardine (*S.longiceps*) using image analysis

The morphometric lengths measured were Total Length(TL), Fork Length(FL), Standard Length(SL), Body depth(BD), Eye diameter(ED), Snout Length(S), Post orbital Length(PL), Head Length(HL) and Caudal Peduncle Height(CPH).


SARDINE PLATE 2

measurements. The method described by Rao *et al.* (1995) was followed here. In all 287 samples of *F. indicus* and 243 samples of *P. monodon* were subjected to this morphometric study. Three lengths namely total length (TL), body length (BL) and carapace length (CL) were measured and recorded as described by Rao *et al.* (1995).

Each one of the prawns were placed inside the image recorder and photographed in JPEG under 2560 x 1920 resolution using the digital camera. The captured images were then transferred to the two computers for storage and further image analysis. The specific image numbers were noted. The image analysis was carried out on the respective numbered images of the specimen of prawn (Plate III, Plate IV) by applying the custom made image analyser software, following the technique described by Arnarson (1991). The algorithm followed was:

Image – filter — calibrate – measure – spreadsheet

3.4.3. Data processing and statistical evaluation

The data obtained, both manual measurements and measurements through image analysis were subjected to data processing. The difference

PLATE III

Calibration and measurement of 3 morphometric lengths
on Prawn (*F.indicus*) using image analysis

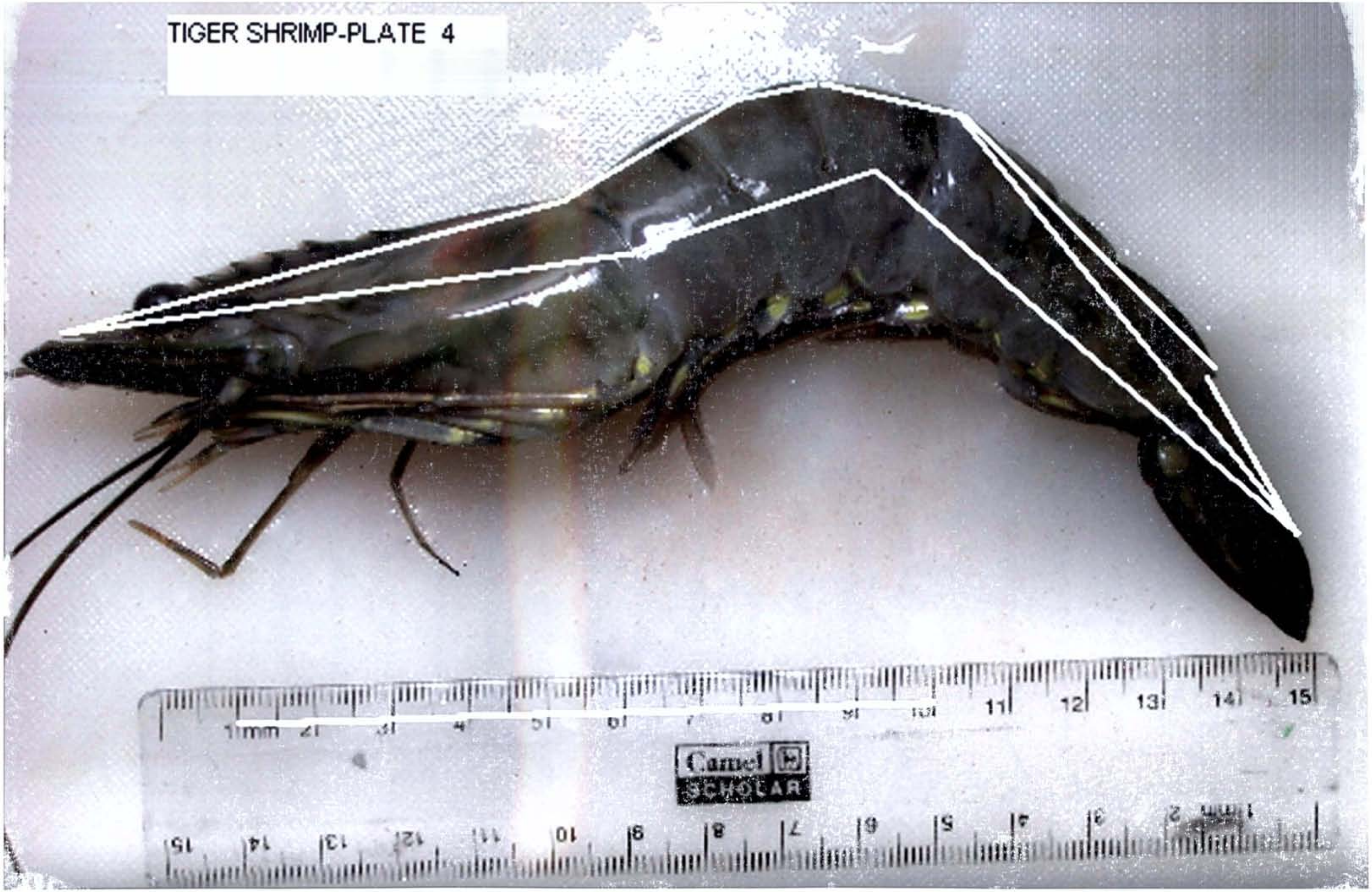
The morphometric lengths measured were Total Length(TL),
Body Length(BL) and Carapace Length(CL).


WHITE SHRIMP-PLATE 3

PLATE IV

Calibration and measurement of . 3 morphometric lengths on Prawn (*P.monodon*) using image analysis

The morphometric lengths measured were Total Length(TL), Body Length(BL) and Carapace Length(CL).


TIGER SHRIMP-PLATE 4
Camel
SCHOLAR

between manual measurement and measurement via the image analysis route was classified into nine class intervals. The manual measurement was taken as the standard since that was the existing and conventional technique. All image analysis measurements showing a higher value than the manual one were classed as positive difference and all image analysis measurements showing a lower value than the manual one were classed as negative difference. All image analysis measurements showing no difference with the manual measurement, including those which showed up to a maximum of one per cent difference were categorised into the zero difference class interval which was set in the middle of the four positive and four negative class intervals thus making up totally nine class intervals. The four class intervals on the positive side of zero difference class interval were 1-3 per cent, 3-5 per cent, 5 -7 per cent and 7-9 per cent difference. A set of four class intervals with the same value range existed on the negative side also The difference obtained in the case of the morphometric measurements by both the manual technique and the image analysis route, be it in the positive for the digital reading, negative for the digital reading or zero showing no difference between the two, were subjected to frequency distribution to check for central tendency if any.

3.5. Measurements on seafood products using image analysis

Seafood products prepared for the market are very many. However, in the case of the present study only a few items where measurement of dimensions are of any significance have been chosen. Cutlets are a very common product in any market. Moulding of cutlets is done in different ways, manually or with the help of moulds, with the moulds differing in size and shape. Two common shapes generally noticed are the elliptical cutlet and the round cutlet. Fish cutlets were prepared in both elliptical and round shape and subjected to manual measurement of dimensions. The dimensions are important indicators of mass. The weight of a cutlet or any similar caterer's product is significant with regard to pricing of the product in the retail outlets like restaurants. The cutlets were also imaged, recorded, transferred and stored for further image analysis studies. An important ingredient in cutlet preparation is the breading material. The breading is usually prepared by pulverising bread toast to a fine powder, but uniformity of particle size may be seriously lacking here. Bread crumbs are also available in the market place. However, the uniformity of the particle size may not be any better in the case of market samples as well. While frying products like fish cutlets or fish fingers or even fish fillets or steaks 'Rava' is an item which is often considered as coating material besides the conventional bread crumb. Samples of bread crumbs and samples of rava were used here for the study to compare the measurement of width of the particles using a microscope and also by the application of image analysis.

3.5.1. Measurements on fish cutlets using image analysis

The standard size of a cutlet is important in terms of its weight. However, for acceptability the appearance of the product is very important. Uniformity of dimensions and undamaged edges are two factors the customer eye most quickly judges. The number of cutlets used for the study were 162.

Manual measurements are only possible using a graduated ruler or a vernier callipers. The method described by Venkataramanujam and Ramanathan (1994) in the case of morphometric length measurements of fish was followed in the length and width measurements for the 162 cutlets here with regard to the manual and conventional technique of measurement.

The measurement of length and width of the cutlets by image analysis was done by capturing the digital images of the cutlets using the digital camera and the image recorder and transferring them onto the computers. The specific image numbers were noted and the length and width of the cutlets were measured through image analysis via the application software (Plate V) described earlier by applying the method described by Arnarson (1991).The algorithm that was followed was the same as what was described for the morphometric measurements on fish and prawns.

The area of the cutlet is also an important measure to ascertain uniformity with regard to chipping away of edges. The chipping away of edges can be detected by comparing the area of the mould or the area of an intact cutlet with the rest of the experimental samples. The method described by Saguy *et al.* (1990) on cookies was applied here. However, instead of superimposition as done by Gagliardi and Sullivan (1983), here the difference in measured area of either the mould or the standard / intact cutlet minus the area of the sample cutlet very clearly gives the area lost to crumbled edges in the manual measurement.

In experiments on area measurements of cutlets through the image analysis route there was no requirement for superimposition of the image of the sample over the standard item, since the data on area was available directly as provided by the software through circular or oval shape descriptors for measurement. The algorithm followed was:

PLATE V

Calibration and measurement of dimensions
of seafood products (cutlets) using image analysis

The dimensions measured were Length, Width and Area

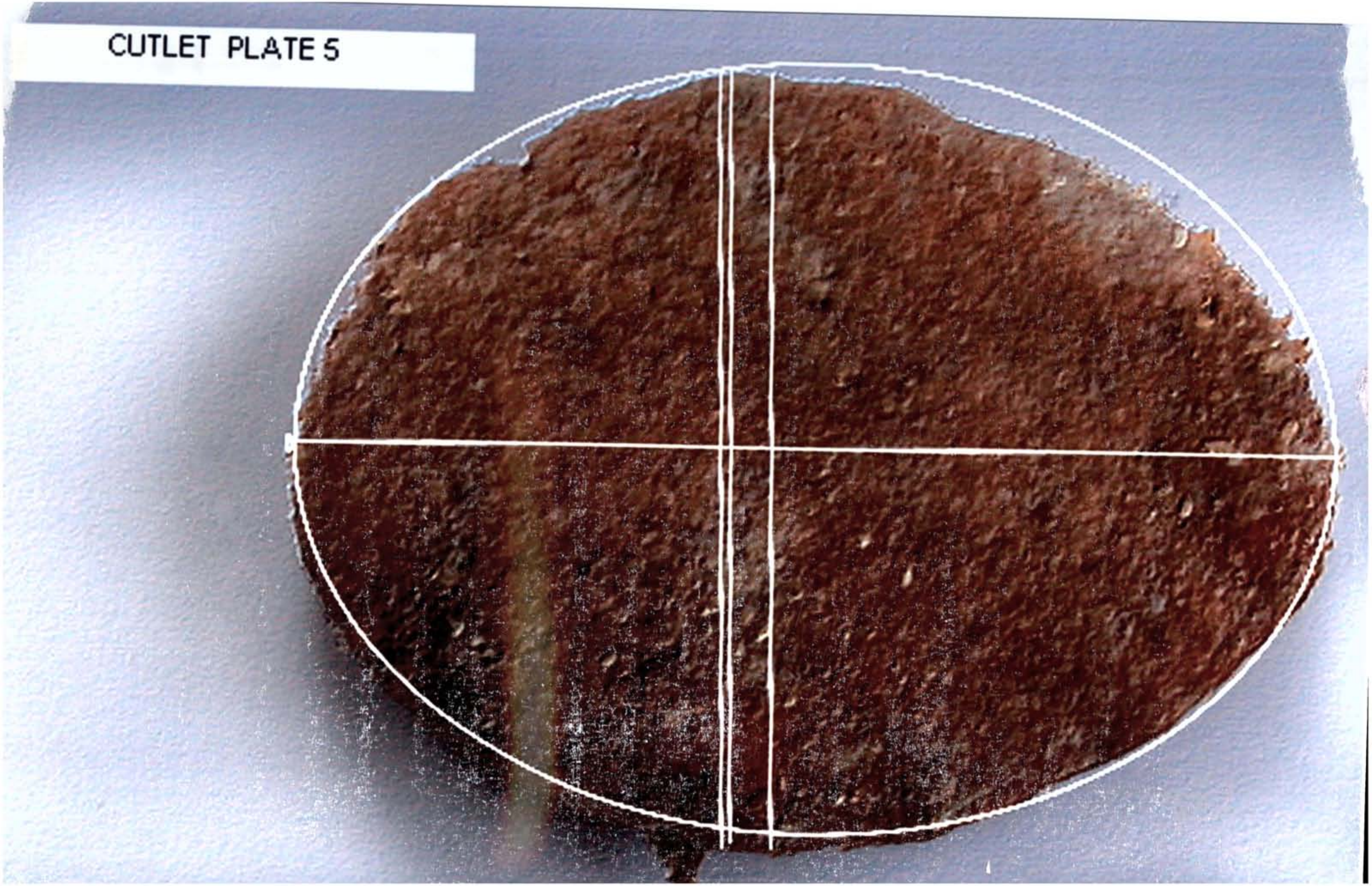

CUTLET PLATE 5

Image – filter—select measure -- area -- circle / oval -- calibrate -- measure

Manually the diameter of circular cutlets were measured using a graduated ruler, graduated to even fractions of millimetre. In the case of oval cutlets the length and width were measured using the same ruler. The area of the mould and the area of the intact cutlet were computed using the mathematical formula for calculating area with the help of a calculator. The area of the broken cutlet was measured by drawing the outline on graph paper and counting the number of squares (Gagliardi and Sullivan,1983).

3.5.2. Measurements on coating materials using image analysis

The cutlet is always battered and then breaded. The material used for breading is highly sophisticated and diverse in content and character in the developed parts of the world, particularly Japan, the U.S and Europe. In India this industry is in its infancy on an industrial level. Hence the availability of a diverse range of quality breading materials is also next to impossible. Thus breading materials are most often conventionally manufactured and hence are often powdered in a grinder and not in a pulveriser resulting in a non-uniform mixture of bread powder. To analyse this, two samples of coating material were selected such as (i) the bread crumb and (ii) market sample of rava (sooji). Seventy samples each of bread crumb and rava were subjected to analysis.

A pinch of the coating material samples both bread crumb and rava were taken each time on a slide and spread well on it. With the help of a lens and a dissection needle three particles were selected. These particles were measured manually under a microscope and their width noted. The slide was then imaged inside the image recorder using the digital camera, the images numbered and transferred to the computer for the image analysis (Plate VI) measurement. Totally 216 particles were measured both manually and by image analysis and the data subjected to statistical evaluation.

3.5.3. Data processing and statistical analysis

Each independent manual measurement in comparison with the corresponding image analysis measurement was also put to frequency distribution to check for the difference either on the positive side for the digital measurement or the negative side or zero difference for it. The manual measurement using the microscope was taken as the standard as it is the conventional, existing method of measurement. The difference shown by the

PLATE VI

Calibration and measurement of particles of
seafood product ingredients using image analysis

The dimensions measured were Width of the particles
Coating materials used were bread crumbs and rava


BREAD CRUMBS - PLATE 6

corresponding image analysis measurements were classified into three groups namely positive difference, negative difference and zero difference numerically. These three classes of data were classified into nine class intervals namely four on the positive side representing 1-3 per cent, 3-5 per cent, 5-7 per cent and 7-9 per cent difference and another similar set of 4 class intervals on the negative side with one class interval representing zero difference in the centre which actually covered a difference of minus one per cent through zero to a plus one per cent.

3.6. Measurements in bacteriology

Bacteriological work generally involves counting the number of colonies while enumerating total bacterial load. The total load is enumerated through the total plate count technique where ideally a colony number ranging between 30 and 300 in a standard sized petri plate is optimum for results of colony counts without serious errors. Samples of total plate count were prepared on standard sized petri plates for counting both manually and by image analysis. Measuring the size of bacterial colonies may become necessary in situations where qualitative determinations are involved. Measurement of colony width or diameter as done conventionally using the microscope can also be carried out using image analysis applications. Antibiotic and disinfectant activity and the relative strength of antibiotics are tested by applying the Kirby-Bauer antibiotic susceptibility test. Test samples were prepared on standard petri plates to plates to carry out measurement of halo diameter using a microscope as well as comparison with the image analysis technique.

3.6.1. Colony counting using image analysis

The existing methods of colony counting namely visually and manually counting the number of colonies after drawing uniform columns on the rear of the standard petri plate or counting the number of colonies by using the colony counter is a reliable technique. However, the counting has to be done at the appropriate time. The application of image analysis in this context has the advantage that counting can be done at any time and after any time gap once the image to be measured is acquired. Besides, both manual and auto counting is possible. Manual counting of colonies was done using the Quebec colony counter as per the technique described by Seeley and VanDemark(1975). A total of 216 plates were used for the study over a period of 2 years. The plates were marked, and each plate was placed on the Quebec colony counter, the number of colonies counted and recorded. Colony counting by image analysis was carried out by imaging all plates one by one inside the image recorder and capturing the digital image in JPEG at 2560 x 1920 resolution. The images were transferred to the computer. The numbered images were then subjected to colony counting by the image analysis route (Plate VII).The algorithm applied was:

image -- filter -- open measure -- select tag -- fix tag size – count

3.6.2 Measurement of colony diameter using image analysis

The colony diameter was manually measured by observing it under the microscope and measuring the diameter using an ocular micrometer which was first standardised using a stage micrometer and then manually recording the value. All 144 colonies were marked and measured. To measure the colony diameter by image analysis, the specific image was opened within the software (Plate VII) and the diameter measured as in the case of all other length measurements described earlier. The algorithm followed was identical to that followed for morphometric measurements.

3.6.3. Measurement of halo diameter using image analysis

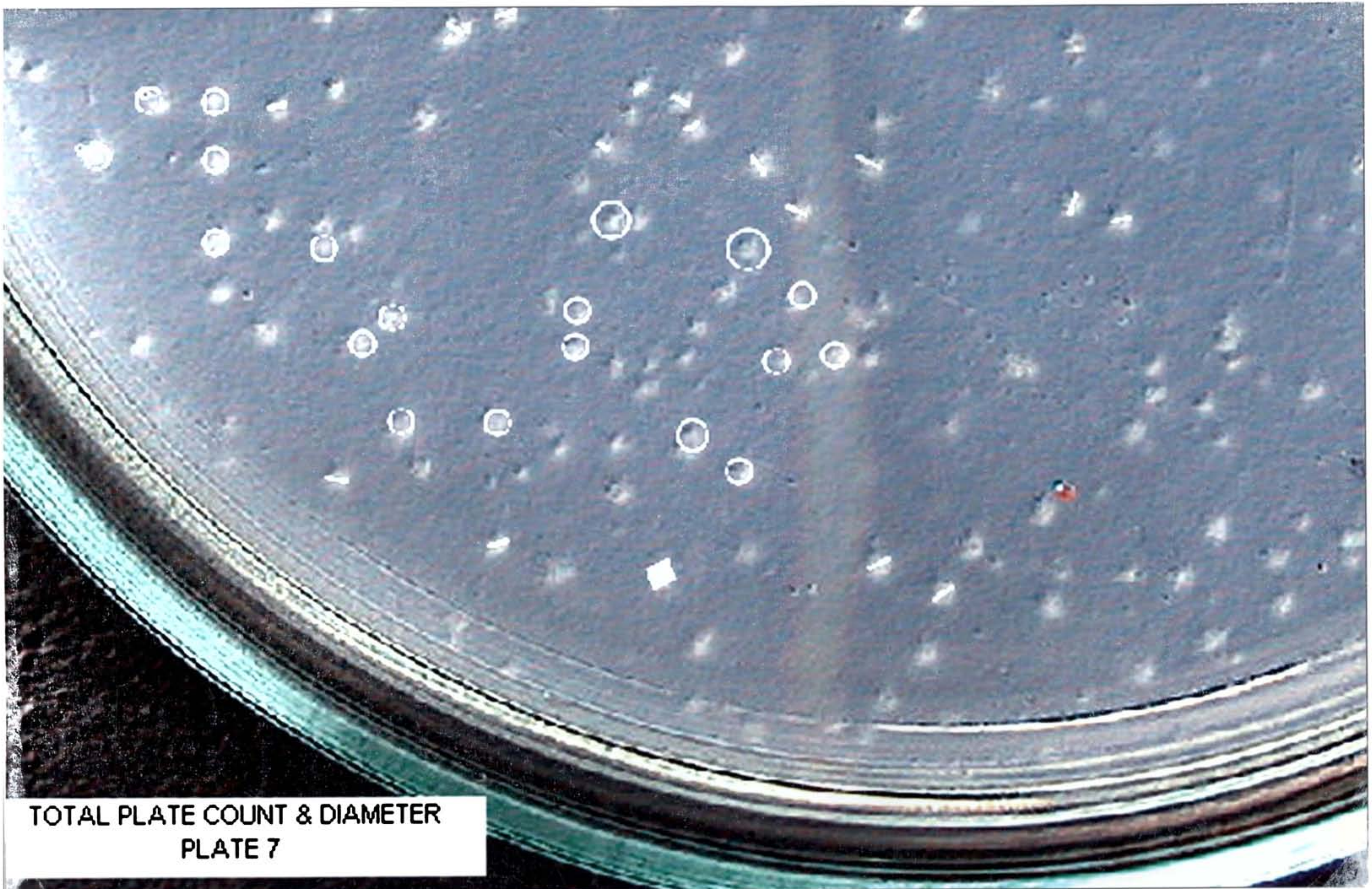
In Microbiological quality evaluations the activity of antimicrobials, antibiotics or disinfectants are often checked using the

PLATE VII

Calibration and measurement of Diameter
of bacterial colonies using image analysis

Counting bacterial colony numbers on
petri plates using image analysis

The circles around the colonies are tags for counting



TOTAL PLATE COUNT & DIAMETER
PLATE 7

microbial inhibition route by placing the antibiotic/antimicrobial impregnated discs on spread plates. The extent of inhibition is indicated by the size of the halo or clear zone developed around the discs and is expressed in terms of halo diameter. Currently the diameter of the clear zone is measured using a graduated ruler (Seeley and VanDemark, 1975). Totally, 270 halo samples on 126 Petri plates were measured manually with a graduated ruler and recorded.

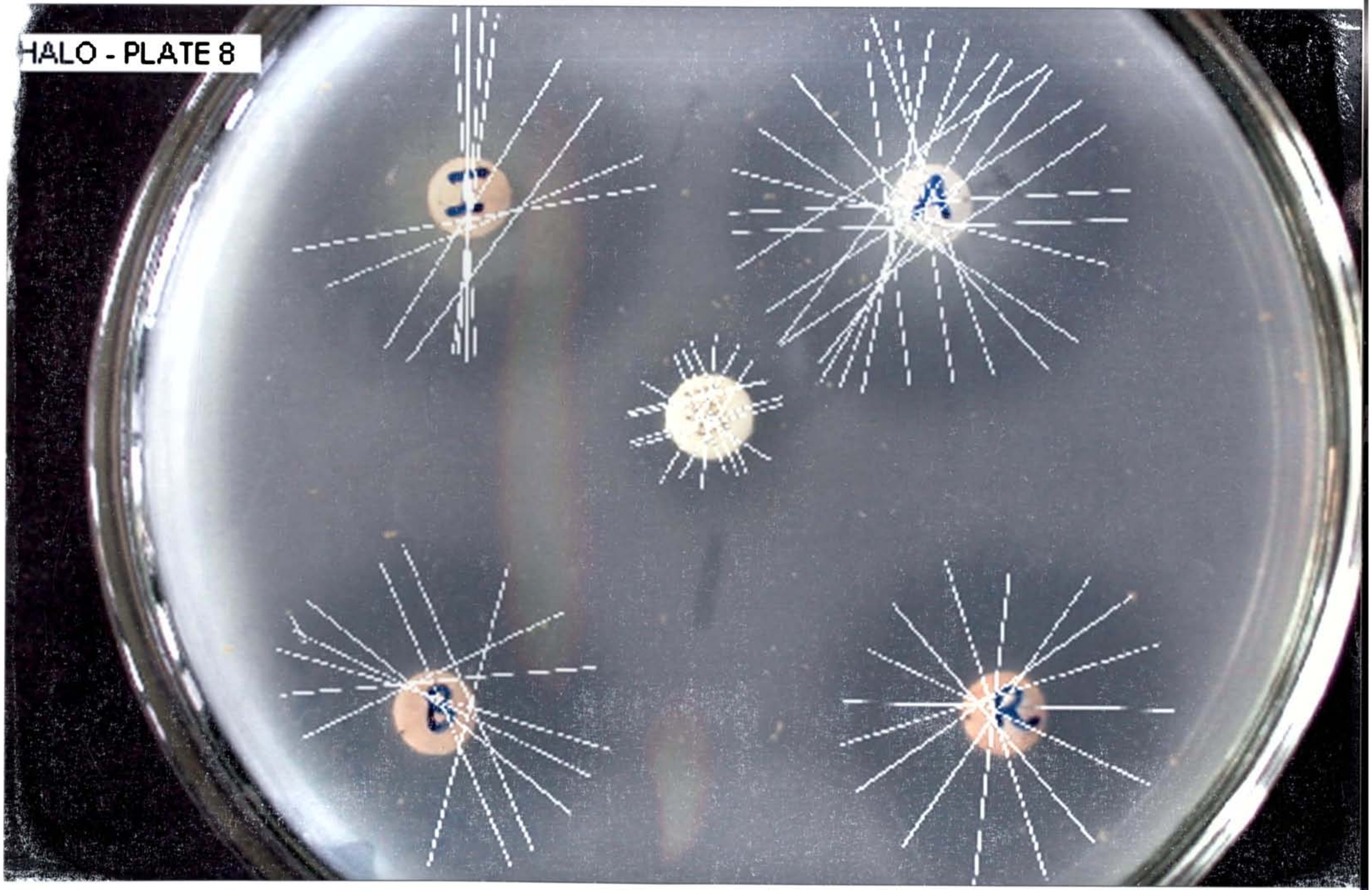
The same 126 Petri plates were digitally photographed in the image recording box and the images transferred to the computer. The numbered images were then subjected to image analysis (Pau and Olafsson, 1991). The algorithm followed was the same as that used for morphometric measurements (Plate VIII).

3.6.4. Data processing and statistical analysis

In all the three cases namely colony counting, bacterial colony diameter measurement and halo diameter measurement the sample numbers were 216 petri plate samples for colony counting, 144 marked bacterial colonies for measurement of colony diameter, and 270 halo samples for measurement of halo diameter. Frequency distribution was applied after processing the data for difference between the two techniques of measurement for any difference on the

PLATE VIII

Calibration and measurement of Halo Diameter
using image analysis


HALO - PLATE 8

positive side, the negative side or zero difference and grouped into nine class intervals as described earlier under morphometric measurements.

3.7. Modelling in size grade determination using image analysis

Through the application of image analysis, size grade determinations can be done very effectively with minimum error. In the case of fish there is an established relationship between length and weight of the same fish. Similarly a relationship should exist between the weight of processed prawn and its diameter. The diameter measurement was to be done using the image analysis technique indicating that quality control could be done in a non-destructive manner and also with minimum or no handling of the samples.

3.7.1. Preparation of the sample

Prawns of various sizes were procured from the markets, landing centres and processing factories to obtain a wide size range. The procurement was carried out gradually and steadily so that it was spread through several months of a calendar year. The collected specimen were graded visually into three categories viz: large , medium and small based on appearance. The prawns were then processed – beheaded, peeled and cooked - as three separate lots of large, medium and small. The cooked prawns were then accurately weighed individually in an electronic balance to the second decimal. Each one of them were then individually imaged using a digital camera. There were twenty four specimen each in the large and medium categories and thirty specimen in the small category.

3.7.2. Image acquisition

Each shrimp sample after cooking and peeling were drained, fan cooled and then photographed. A digital camera Nikon coolpix 5000 was used for the purpose. The image capturing was carried out by placing the cooked shrimp flat on a white cutting board within a box of dimensions 36.5 cm height, 27.5 cm width and 20.5 cm depth with its inner walls covered with matt finish white paper and with 8W, 10 lux illumination using a CFL lamp. The camera was placed at a fixed height atop the box with the lens protruding through a hole provided centrally at the top of the box. The photographs were captured in macro lens mode and without flash function in the JPEG format with resolution 2560 x 1920 pixels. TIFF format is not essential for this type of work since huge enlargements are not necessary here and it would also amount to unnecessarily loading the processor with excess quantum of data to deal with.

3.7.3. Image transfer

The images were acquired into a 128 MB flash card and were then transferred to a computer for further image analysis work. Back up of the images was taken. The computer used had 512 RAM, 3.2 GHz clock speed and n-video graphics for image processing. Lower specifications would suffice. Also a laptop Toshiba PIII Satellite 3000 A 424 of 1 GHz clock speed, 256 MB RAM and 16 MB Video RAM with a graphics controller 4x AGP NVIDIA GE Force 2 Graphics card and IEEE Port was used for the image analysis work.

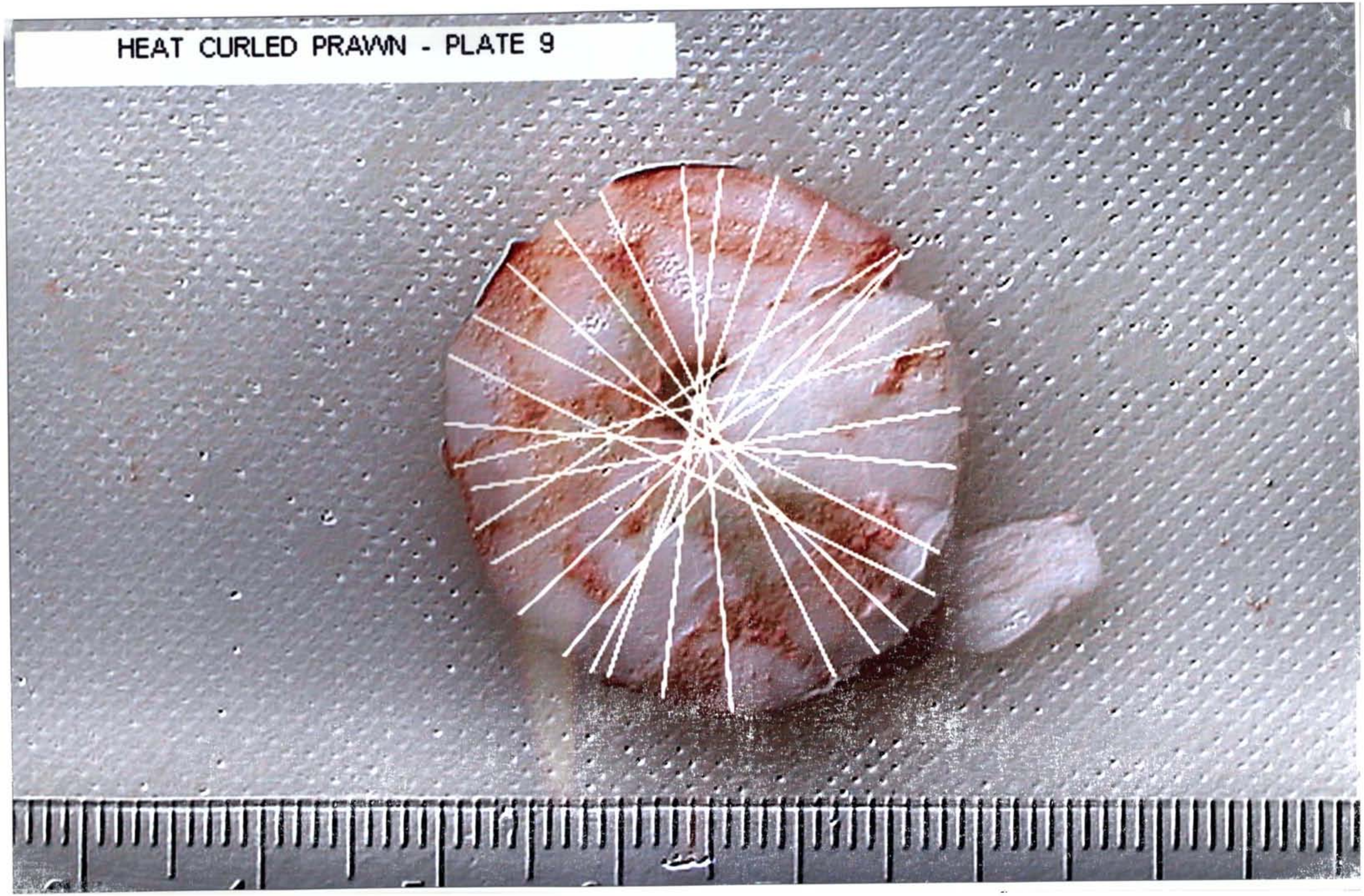
3.7.4. Image analysis

Image analysis was carried out using a custom made image analyser software capable of executing both virtual and real scale measurements, had spread sheets to automatically transfer data and record them and also had statistical tools to carryout analysis. All tools were available in the form of user friendly pull down menus.

Image analysis in this context involved real (Plate IX) scale diameter measurements. Ten measurements were taken for each image and averaged. This average was taken as the diameter in centimetre. Each

PLATE IX

Calibration and measurement of Diameter of heat curled prawn for estimating weight using image analysis


HEAT CURLED PRAWN - PLATE 9

measurement was carried out in real scale. Thirty such average diameter readings were gathered as data for the "small" lot and twenty four each for the "medium" and "large" lots. The images were transferred to the computer for image analysis work. The stored images were selected one by one for image analysis, subjected to necessary filtering and/or noise reduction as the case maybe and readied for the diameter measurements. Diameter–weight data were gathered separately for every specimen under the large, medium and small category. This data was then put to statistical analysis for developing suitable models.

3.7.5. Statistical analysis and mathematical modelling

Data pertaining to diameter (cm) and weight (g) of the sample of prawns were collected accurately. Since the accurate weighing of prawns is very tedious during routine production in the seafood processing factory, a statistical model was developed for the estimation of weight using diameter data. For this, the data were subjected to simple linear regression analysis with diameter (D) as the independent variable and weight (W) as the dependent variable.

Separate models were developed for the large, medium and small categories of peeled, de-veined and cooked shrimp. The goodness of fit of the models was assessed using two statistical criteria, namely Coefficient of determination (R^2) and Standard Error of the Estimate. The statistical analysis was carried out using the software SPSS version.14.0.

3.7.6. Audit and verification

The models so developed using statistical tools were subjected to audit and verification. Individual average diameter readings were substituted in the respective formulae to compute the weight. The estimated weights were then compared with the actual weights found using an electronic digital balance. Statistical tool such as correlation coefficient was used for this. An entirely new set of samples were used for the verification studies.

4. RESULTS

The experimental work consisted entirely of comparisons between manual methods of measurement of certain quality related aspects, and the application of image analysis techniques in the measurement of the same. The present study involved systematic morphometric measurements on fishes and prawns as well as quality related measurements on product size and shape, besides particle and object analysis. The application of image analysis in mathematical modelling for size grade determination was also tested.

4.1.Morphometric measurements

Totally, nine standard morphometric measurements were done on fish as described by Venkataramanujam and Ramanathan (1994). Two species of fish, the Indian Mackerel (*Rastrelliger kanagurta*) and the Indian Oil Sardine (*Sardinella longiceps*) were selected for the study. The measurements done were total lengh, fork length, standard length, body depth, snout, eye diameter, post orbital, head length, and caudal peduncle. In the case of prawns, the method described by Rao et al. (1995) was followed. Two species viz: *F. indicus* and

Penaeus monodon were selected for the study. Only three morphometric measurements were carried out on prawns namely total length, body length and carapace length. Both manual measurements and measurements by image analysis were recorded and their difference computed. Manual measurement was taken as the standard since it is the existing and established method. The difference shown by image analysis measurement was recorded as any one of the following viz: zero / positive / negative. The comparisons between the two techniques of measurement and the relative differences between variations obtained for all the 9 standard lengths measured should provide meaningful interpretations only if the difference was expressed in percentage and not in actual length. The data thus processed was put to frequency distribution. The zero difference was marked within one per cent range on both the positive side and negative side. Nine class intervals were thus obtained; four class intervals on the positive side, four of them on the negative side and one at the centre representing zero difference which included a one percent positive difference as well as a one percent negative diference. Variation between the two techniques of measurement upto a difference of nine per cent on both the positive and negative side was represented by histograms.

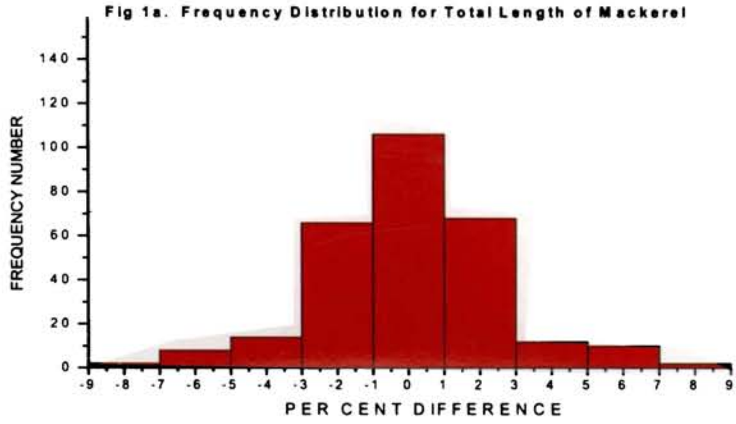
4.1.1. Morphometrics on Mackerel

The morphometric measurements on mackerel was carried out for nine different length measurements. In total 288 fishes were subjected to measurement both manually and by image analysis. The difference between the two was computed, converted into percentage and expressed as frequency distribution into nine class intervals, four on the positive side and four on the negative, on either side of zero represented by histograms. In the case of total length, 51 per cent readings (147 nos. out of the 288 total nos.) showed no difference and 31per cent showed a difference of less than 3 per cent. While 14 per cent showed a difference less than 5 per cent, only 4 per cent showed a difference of less than 7 per cent in values (Table1, Fig.1a).

Table 1. Frequency distribution of total length of Mackerel

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	9
+3.0 to + 5.0	18
+1.0 to + 3.0	46
-1.0 to + 1.0	147
-1.0 to - 3.0	42
-3.0 to - 5.0	23
-5.0 to - 7.0	3
-7.0 to - 9.0	0
Total	288

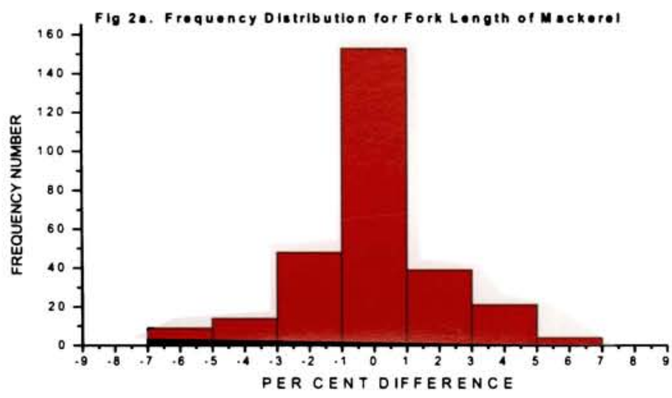
Fig 1a. Frequency Distribution for Total Length of Mackerel



In the case of fork length 53 per cent showed no difference (153 nos. out of 288 nos.) and 30 per cent showed less than 3 per cent difference. While 12 per cent was seen to show a difference of 5 per cent, about 4.5 per cent only displayed a difference of 7 per cent (Table2, Fig.2a).

Table 2. Frequency distribution of fork length of Mackerel

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	4
+3.0 to +5.0	21
+1.0 to + 3.0	39
-1.0 to + 1.0	153
-1.0 to - 3.0	48
-3.0 to - 5.0	14
-5.0 to - 7.0	9
-7.0 to - 9.0	0
Total	288



In the case of standard length, the no-difference range was represented by 47 per cent of the readings and 33 per cent accounted for a difference below 3 per cent. While 16 per cent accounted for below 5 per cent difference, 4 per cent showed less than 7 per cent difference in the readings. Also a meagre 0.7 per cent of the measurements stood in the under 9 per cent range (Table3, Fig.3a).

Table 3.Frequency distribution of standard length of Mackerel

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	2
+5.0 to + 7.0	2
+3.0 to + 5.0	27
+1.0 to + 3.0	49
-1.0 to + 1.0	135
-1.0 to - 3.0	45
-3.0 to - 5.0	18
-5.0 to - 7.0	10
-7.0 to - 9.0	0
Total	288

For body depth measurements, while 38 per cent showed no difference about 35 per cent showed under 3 per cent difference and 19 per cent showed below 5 per cent difference. The difference in the case of 6 per cent of the readings was below

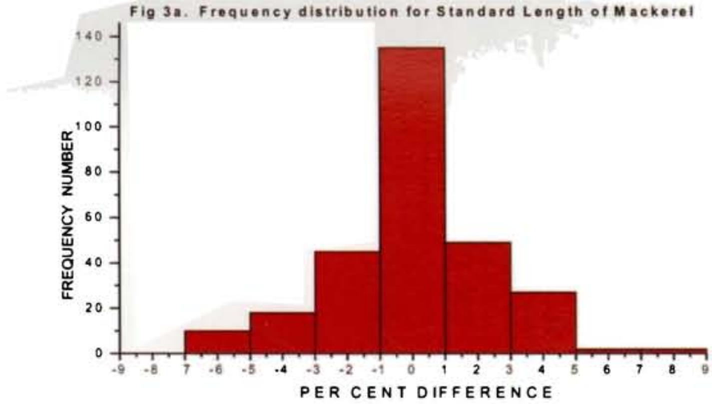


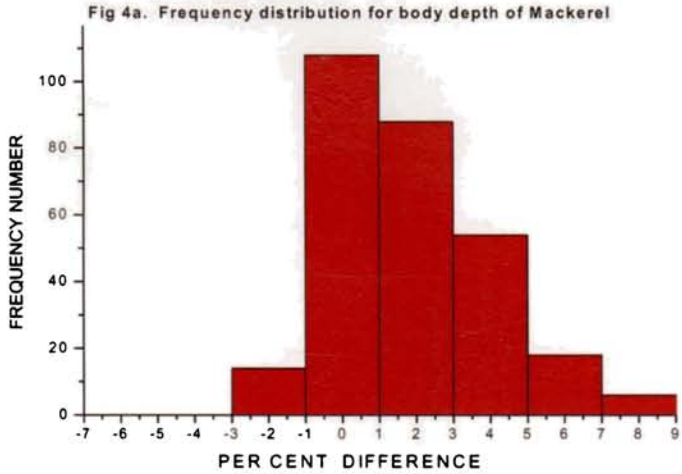
Fig 3a. Frequency distribution for Standard Length of Mackerel

7 per cent and a meagre 2 per cent represented the range of difference within 9 per cent. The readings were specifically skewed towards the positive side. Only 5 per cent of the image analysis readings were lower than the manual readings, and 95 per cent of them showed values higher than the manual measurements, T an aberration seen in the case of body depth measurements (Table4, Fig.4a) Snout length measurements showed 30 per cent with no difference, 52 per cent with less than 3 per cent difference, 11 per cent with under 5 per cent difference

Table 4. Frequency distribution of body depth of Mackerel

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	6
+5.0 to + 7.0	18
+3.0 to + 5.0	54
+1.0 to + 3.0	88
-1.0 to + 1.0	108
-1.0 to - 3.0	14
-3.0 to - 5.0	0
-5.0 to - 7.0	0
-7.0 to - 9.0	0
Total	288

Fig 4a. Frequency distribution for body depth of Mackerel

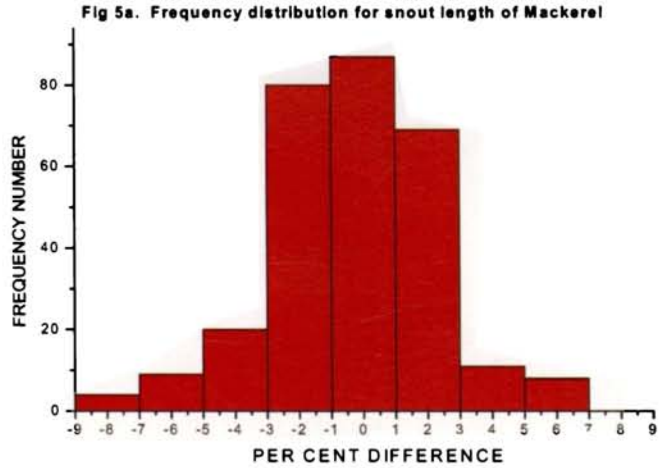


and 6 percent with below 7 per cent difference. The readings showing an under 9 per cent difference was a meagre 1 per cent (Table5, Fig.5a).

Table 5. Frequency distribution of snout length of Mackerel

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	8
+3.0 to +5.0	11
+1.0 to + 3.0	69
-1.0 to + 1.0	87
-1.0 to - 3.0	80
-3.0 to - 5.0	20
-5.0 to - 7.0	9
-7.0 to - 9.0	4
Total	288

Fig 5a. Frequency distribution for snout length of Mackerel

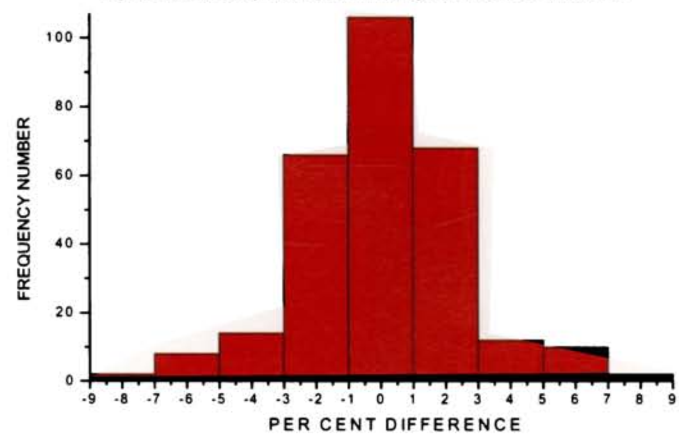


Eye diameter measurement showed the following trend. While 34 per cent showed no difference, 38 per cent showed less than 3 per cent difference. In the case of below 5 per cent difference the value was 18.5 per cent, while 10 per cent showed a less than 7 per cent difference (Table 6, Fig.6a).

Table 6. Frequency distribution of eye diameter of Mackerel

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	16
+3.0 to + 5.0	17
+1.0 to + 3.0	63
-1.0 to + 1.0	99
-1.0 to - 3.0	45
-3.0 to - 5.0	36
-5.0 to - 7.0	12
-7.0 to - 9.0	0
Total	288

Fig 6a. Frequency distribution for eye diameter of Mackerel

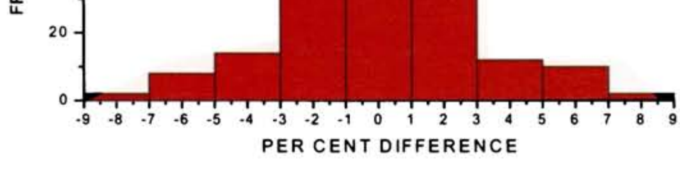


Post orbital length measurement when analysed showed that 37 per cent had no difference, while 47 per cent showed less than 3 per cent difference. Less than 5 per cent difference was represented by 9 per cent of the measurements while 6 per cent readings fell in the under 7 per cent difference range and a paltry 1.4 per cent represented the under 9 per cent difference (Table7, Fig.7a).

Table7. Frequency distribution of post orbital length of Mackerel

Frequency range (percent)	Frequency (No. of fishes)
+7.0 to + 9.0	2
+5.0 to + 7.0	10
+3.0 to +5.0	12
+1.0 to + 3.0	68
-1.0 to + 1.0	106
-1.0 to - 3.0	66
-3.0 to - 5.0	14
-5.0 to - 7.0	8
-7.0 to - 9.0	2
Total	288

Fig 7a. Frequency distribution for post orbital length of Mackerel

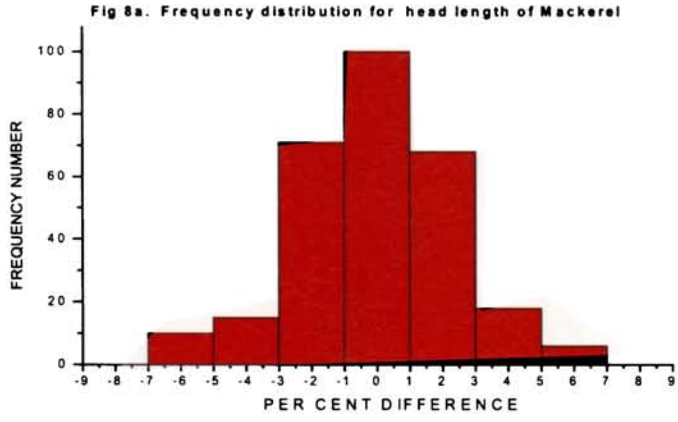


In the case of head length, while 35 per cent represented no difference, 48 per cent showed a difference of only under 3 per cent, 11.5 per cent showed a difference of under 5 per cent and 5.5 per cent showed an under 7 per cent difference (Table8, Fig.8a).

Table 8. Frequency distribution of head length of Mackerel

Frequency range (percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	6
+3.0 to + 5.0	18
+1.0 to + 3.0	68
-1.0 to + 1.0	100
-1.0 to - 3.0	71
-3.0 to - 5.0	15
-5.0 to - 7.0	10
-7.0 to - 9.0	0
Total	288

Fig 8a. Frequency distribution for head length of Mackerel

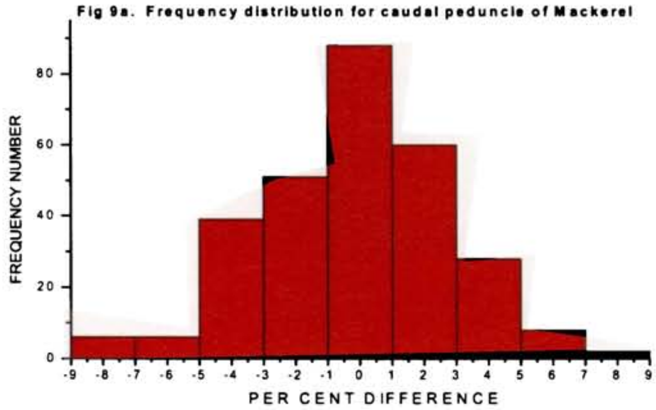


Caudal peduncle measurements showed no difference for 31 per cent of the readings and below 3 per cent for 39 per cent. Below 5 per cent difference was shown by 23 per cent, while 5 per cent displayed less than 7 per cent difference. Under 9 per cent difference was shown by 3 per cent only (Table 9, Fig.9a).

Table 9. Frequency distribution of caudal peduncle of Mackerel

Frequency range (percent)	Frequency (No. of fishes)
+7.0 to + 9.0	2
+5.0 to + 7.0	8
+3.0 to + 5.0	28
+1.0 to + 3.0	60
-1.0 to + 1.0	88
-1.0 to - 3.0	51
-3.0 to - 5.0	39
-5.0 to - 7.0	6
-7.0 to - 9.0	6
Total	288

Fig 9a. Frequency distribution for caudal peduncle of Mackerel



4.1.2.Morphometrics on sardines

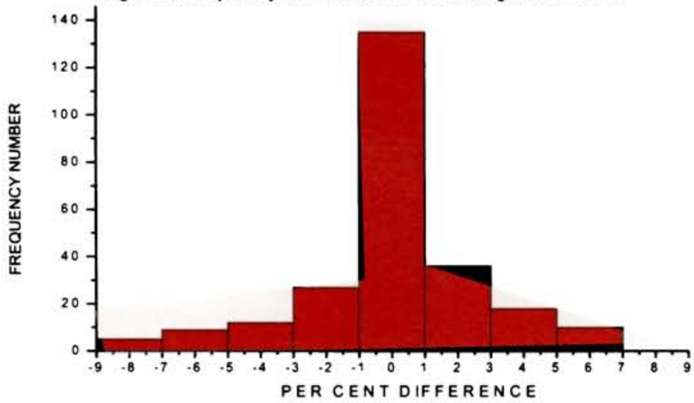
Sardines were also subjected to morphometric measurements of 9 different measurements namely total length, fork length, standard length, body depth, snout, eye diameter, post orbital, head length and caudal peduncle. In all 252 number of sardines were subjected to this study. The measurements were carried out manually and by image analysis and the difference computed and percentage difference determined. The differences thus obtained were categorised into 9 class intervals of percentage difference, the zero difference falling within one percent on both the higher side and lower side of zero and the remaining 8 class intervals four on the positive for higher image analysis readings and four on the negative accounting for lower image analysis readings from the conventional manual measurements which was taken here as standard to compute the variations of the image analysis readings for the comparative study.

Total length measurement revealed that 54 per cent of the fishes measured showed no difference while 25 per cent showed a difference of 3 per cent. A below 5 per cent difference in the readings was recorded in the case of 12 per cent of measurements, a less than 7 per cent difference was noted in the case of 7.5 per cent of measurements and an under 9 per cent difference was recorded by 2 per cent of the measurements while comparing manual measurements against image analysis based measurements (Table10, Fig.10a).

Table 10. Frequency distribution of total length of Sardines

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	10
+3.0 to + 5.0	18
+1.0 to + 3.0	36
-1.0 to + 1.0	135
-1.0 to - 3.0	27
-3.0 to - 5.0	12
-5.0 to - 7.0	9
-7.0 to - 9.0	5
Total	252

Fig 10a. Frequency distribution for total length of Sardine

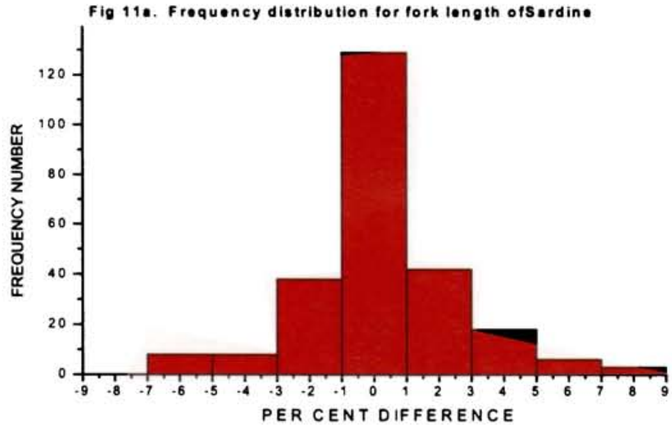


While measuring fork length it was noticed that 51 per cent of the measurements showed no difference, 32 per cent showed a difference of under 3 per cent and 11 per cent showed under 5 per cent difference. While 6 per cent of measurements showed under 7 per cent difference a meagre 1 per cent only showed a difference between 7 and 9 per cent (Table 11, Fig.11a).

Table 11. Frequency distribution of fork length of Sardines

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	3
+5.0 to + 7.0	6
+3.0 to +5.0	18
+1.0 to + 3.0	42
-1.0 to + 1.0	129
-1.0 to - 3.0	38
-3.0 to - 5.0	8
-5.0 to - 7.0	8
-7.0 to - 9.0	0
Total	252

Fig 11a. Frequency distribution for fork length ofSardine

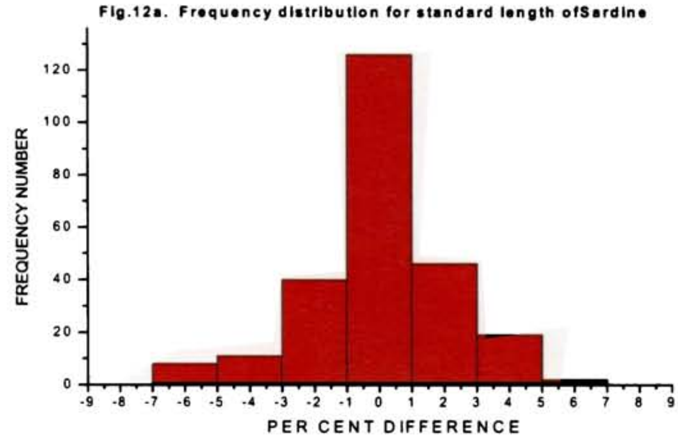


Morphometrics of standard length showed that 50 per cent of measurements had no difference, 34 per cent showed a difference under 3 per cent, 12 per cent below 5 per cent and 4 per cent only showed a difference under 7 per cent (Table12, Fig.12a).

Table 12. Frequency distribution of standard length of Sardines

Frequency range(percent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	2
+3.0 to + 5.0	19
+1.0 to + 3.0	46
-1.0 to + 1.0	126
-1.0 to - 3.0	40
-3.0 to - 5.0	11
-5.0 to - 7.0	8
-7.0 to - 9.0	0
Total	252

Fig.12a. Frequency distribution for standard length ofSardine

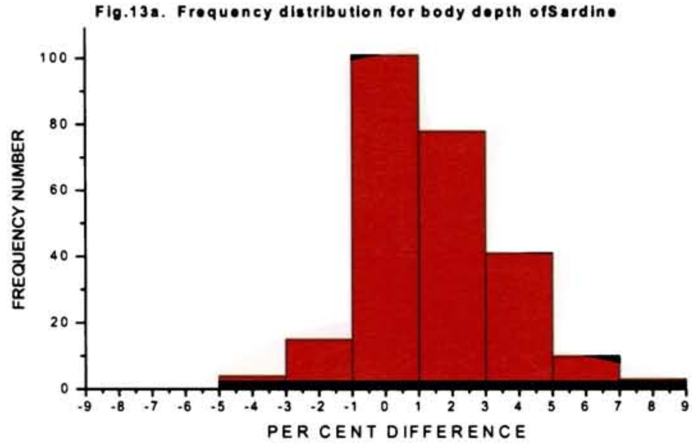


Body depth measurements showed that 40 per cent of the measurements had no difference, 37 per cent had a difference below 3 per cent, 18 per cent were below 5 per cent and 4 per cent between 5 and 7 per cent. A difference of 7 to 9 per cent was shown by a paltry 1 per cent only (Table 13, Fig.13a).

Table 13. Frequency distribution of body depth of Sardines

Frequency range (per cent)	Frequency (No. of fishes)
+7.0 to + 9.0	3
+5.0 to + 7.0	10
+3.0 to +5.0	41
+1.0 to + 3.0	78
-1.0 to + 1.0	101
-1.0 to -3.0	15
-3.0 to -5.0	4
-5.0 to -7.0	0
-7.0 to -9.0	0
Total	252

Fig.13a. Frequency distribution for body depth ofSardine

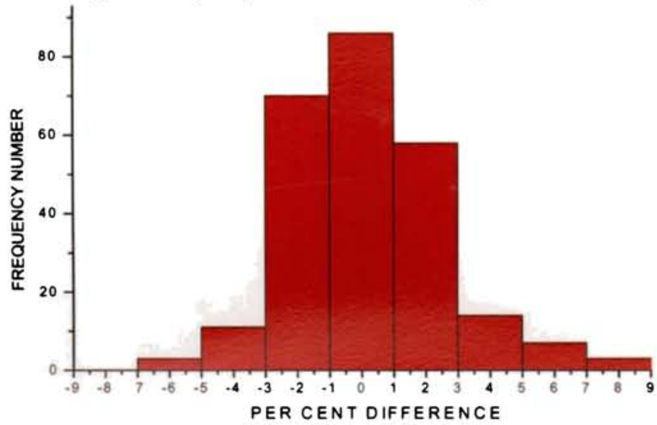


The entire readings of body depth was found skewed towards the positive side showing that only 7.5 per cent of the image analysis measurements were less than the manual measurements. The entire remaining 92.5 per cent of the measurements showed a higher value than manual measurements. Measurement of snout length showed that 34 per cent of the measurements had no difference, while 51 per cent of the measurements showed a difference of under 3 per cent only. A difference of under 5 per cent between the two techniques of measurement was shown by 10 per cent of the readings and a difference of under 7 per cent and under 9 per cent by 4 per cent and 1 per cent of the measurements respectively (Table 14, Fig.14a).

Table 14. Frequency distribution of snout length of Sardines

Frequency range (per cent)	Frequency (No. of fishes)
+7.0 to + 9.0	3
+5.0 to + 7.0	7
+3.0 to + 5.0	14
+1.0 to + 3.0	58
-1.0 to + 1.0	86
-1.0 to - 3.0	70
-3.0 to - 5.0	11
-5.0 to - 7.0	3
-7.0 to - 9.0	0
Total	252

Fig.14a. Frequency distribution for snout length ofSardine

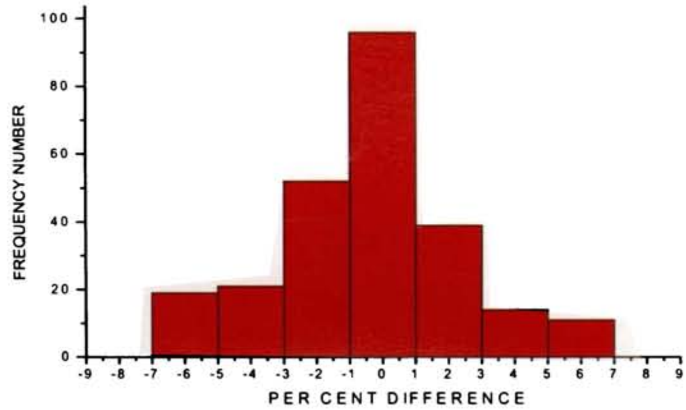


Morphometrics of eye diameter showed that 38 per cent of the measurements had no difference. However, 36 per cent, 14 per cent and 12 per cent of the measurements showed differences of under 3 per cent, under 5 per cent and under 7 per cent respectively (Table 15, Fig.15a).

Table 15. Frequency distribution of eye diameter of Sardines

Frequency range (per cent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	11
+3.0 to + 5.0	14
+1.0 to + 3.0	39
-1.0 to + 1.0	96
-1.0 to - 3.0	52
-3.0 to - 5.0	21
-5.0 to - 7.0	19
-7.0 to - 9.0	0
Total	252

Fig.15a. Frequency distribution for eye diameter ofSardine

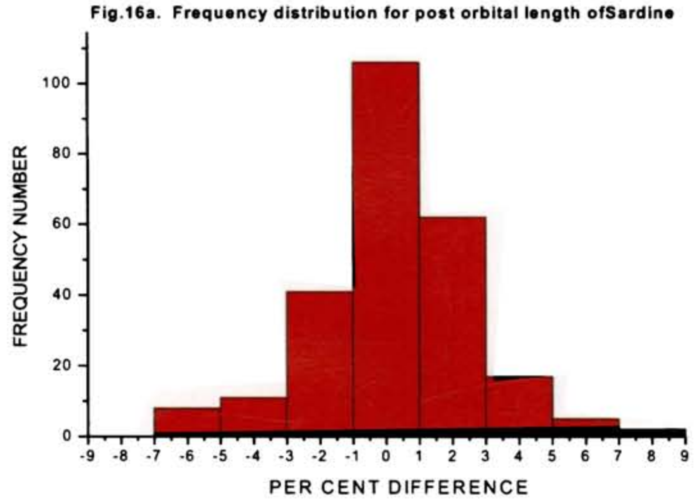


Measurements of post orbital length revealed that 42 per cent of the measurements had no difference. This was closely followed by a difference of under 3 per cent shown by 41 per cent of the measurements done under the two different techniques. However, 11 per cent of measurements showed a difference below 5 per cent while 5 per cent of the readings showed a difference below 7 per cent and only a meagre 0.8 per cent of them showed a difference under 9 per cent. The differences detected between the conventional manual method of measurement and the image analysis technique of measurement is shown in the table and graph (Table16, Fig.16a).

Table 16. Frequency distribution of post orbital length of Sardines

Frequency range (per cent)	Frequency (No. of fishes)
+7.0 to + 9.0	2
+5.0 to + 7.0	5
+3.0 to + 5.0	17
+1.0 to + 3.0	62
-1.0 to + 1.0	106
-1.0 to - 3.0	41
-3.0 to - 5.0	11
-5.0 to - 7.0	8
-7.0 to - 9.0	0
Total	252

Fig.16a. Frequency distribution for post orbital length ofSardine

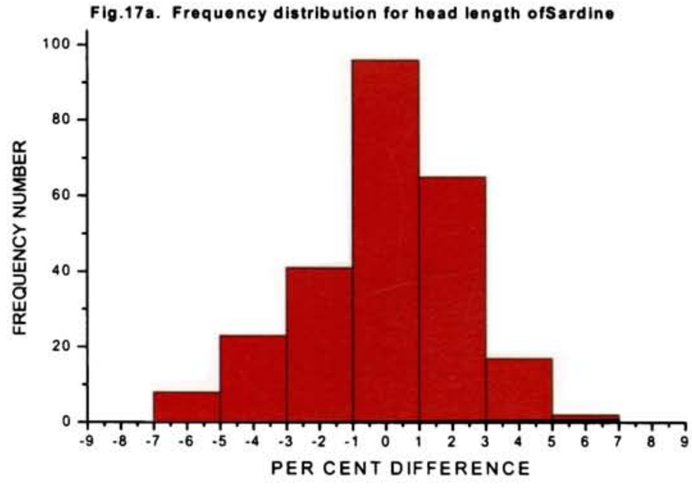


For head length measurements 38 per cent of the readings showed no difference. However, 42 per cent showed a difference under 3 per cent and 16 per cent and 4 per cent measurements showed a difference of under 7 per cent and 9 per cent respectively. (Table17, Fig.17a).

Table 17. Frequency distribution of head length of Sardines

Frequency range (per cent)	Frequency (No. of fishes)
+7.0 to + 9.0	0
+5.0 to + 7.0	2
+3.0 to + 5.0	17
+1.0 to + 3.0	65
-1.0 to + 1.0	96
-1.0 to - 3.0	41
-3.0 to - 5.0	23
-5.0 to - 7.0	8
-7.0 to - 9.0	0
Total	252

Fig.17a. Frequency distribution for head length ofSardine

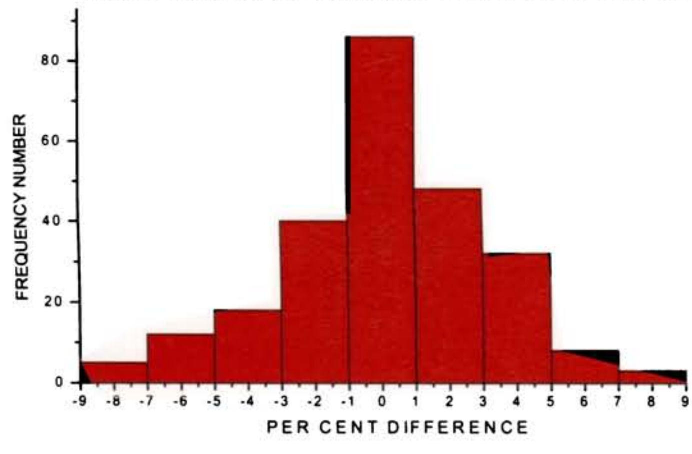


For the last item namely caudal peduncle, the results were as follows. 34 per cent of the measurements had no difference, while 35 per cent showed only a difference of under 3 per cent. Meanwhile, 20 per cent, 8 per cent and 3 per cent of the measurements showed a difference of less than 5 per cent, less than 7 per cent and under 9 per cent respectively (Table 18, Fig.18a).

Table 18. Frequency distribution of caudal peduncle of Sardines

Frequency range (per cent)	Frequency (No. of fishes)
+7.0 to + 9.0	3
+5.0 to + 7.0	8
+3.0 to + 5.0	32
+1.0 to + 3.0	48
- 1.0 to + 1.0	86
- 1.0 to - 3.0	40
- 3.0 to - 5.0	18
- 5.0 to - 7.0	12
- 7.0 to - 9.0	5
Total	252

Fig.18a. Frequency distribution for caudal peduncle ofSardine



4.1.3. Mophometric measurements on *Fenneropenaeus indicus*

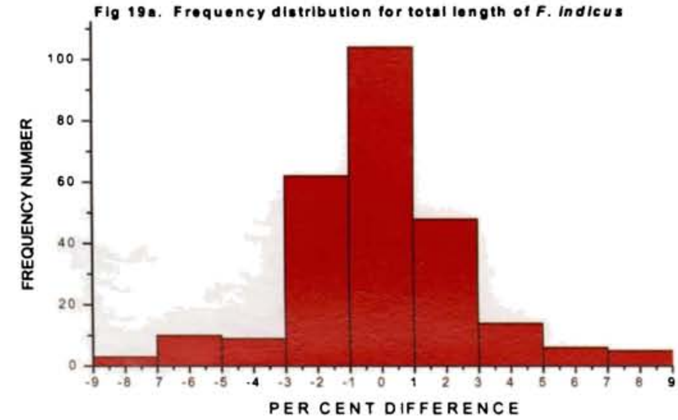
While total length measurements showed that 40 per cent of readings had no difference, 42 per cent had only under 3 per cent difference. Measurements accounting for 9 per cent of the total showed an under 5 per cent difference and 6 per cent of the measurements recorded had under 7 per cent difference. Only 3 per cent of readings accounted for 7 to 9 per cent difference as shown in detail in Table 19, Fig.19a.

Table 19. Frequency distribution of total length of *F.indicus*

Frequency range (per cent)	Frequency (No. of prawns)
+7.0 to + 9.0	5
+5.0 to + 7.0	6
+3.0 to +5.0	14
+1.0 to + 3.0	48
-1.0 to + 1.0	104
-1.0 to -3.0	62
-3.0 to -5.0	9
-5.0 to -7.0	10
-7.0 to -9.0	3
Total	261

Body length measurements also followed a closely similar pattern. 43 per cent of measurements showed no difference and the under 3 per cent difference

Fig 19a. Frequency distribution for total length of *F. indicus*

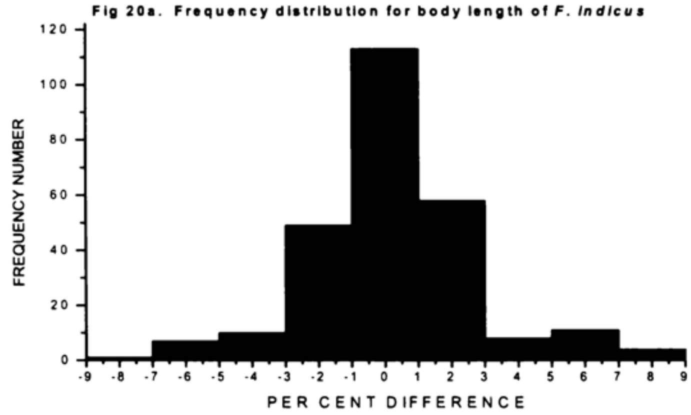


was shown by a close 41 per cent. Differences of 3 to 5 per cent, 5 to 7 per cent and 7 to 9 per cent were shown by 7 per cent, 7 per cent and 2 per cent of the readings respectively (Table20, Fig.20a).

Table 20. Frequency distribution of body length of *F.indicus*

Frequency range (per cent)	Frequency (No. of prawns)
+7.0 to + 9.0	4
+5.0 to + 7.0	11
+3.0 to +5.0	8
+1.0 to + 3.0	58
-1.0 to + 1.0	113
-1.0 to -3.0	49
-3.0 to -5.0	10
-5.0 to -7.0	7
-7.0 to -9.0	1
Total	261

Fig 20a. Frequency distribution for body length of *F. indicus*

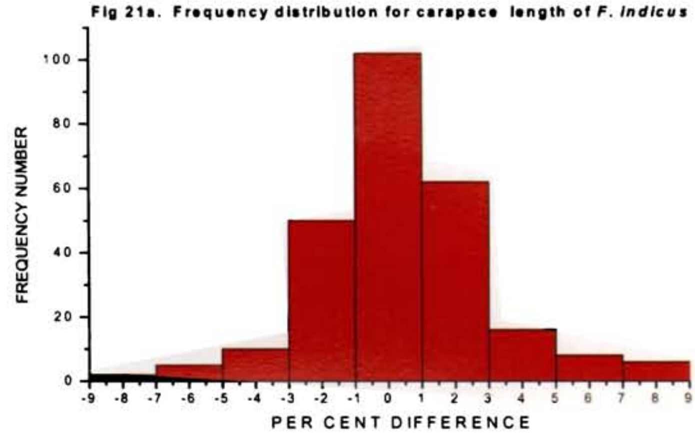


Morphometrics on carapace length revealed that 39 per cent of measurements showed no difference, while 43 per cent had a less than 3 per cent difference. A difference of 3 to 5 per cent, 5 to 7 per cent and 7 to 9 per cent was shown by 10 per cent, 5 per cent and 3 per cent of the measurements respectively (Table 21, Fig. 21a).

Table 21.Frequency distribution of carapace length of *F.indicus*

Frequency range (per cent)	Frequency (No. of prawns)
+7.0 to + 9.0	6
+5.0 to + 7.0	8
+3.0 to +5.0	16
+1.0 to + 3.0	62
-1.0 to + 1.0	102
-1.0 to -3.0	50
-3.0 to -5.0	10
-5.0 to -7.0	5
-7.0 to -9.0	2
Total	261

Fig 21a. Frequency distribution for carapace length of *F. indicus*



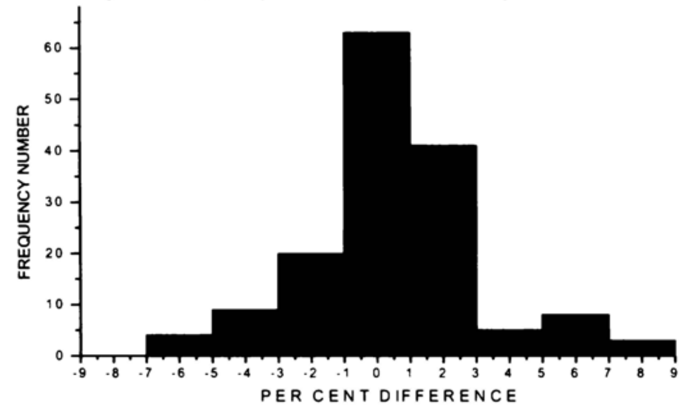
4.1.4. Morphometric measurements on *Penaeus monodon*

In the case of total length no difference was shown by 41 per cent of the readings and less than 3 per cent difference ran a close second of 40 per cent. The 3-5 per cent, the 5-7 per cent and the 7-9 per cent difference was accounted for by 9, 8 and 2 per cent of the measurements respectively (Table22, Fig.22a).

Table 22. Frequency distribution of total length of *P.monodon*

Frequency range(percent)	Frequency (No. of prawns)
+7.0 to + 9.0	3
+5.0 to + 7.0	8
+3.0 to +5.0	5
+1.0 to + 3.0	41
- 1.0 to + 1.0	63
- 1.0 to - 3.0	20
- 3.0 to - 5.0	9
- 5.0 to - 7.0	4
- 7.0 to - 9.0	0
Total	153

Fig.22a Frequency distribution for total length of *P.monodon*

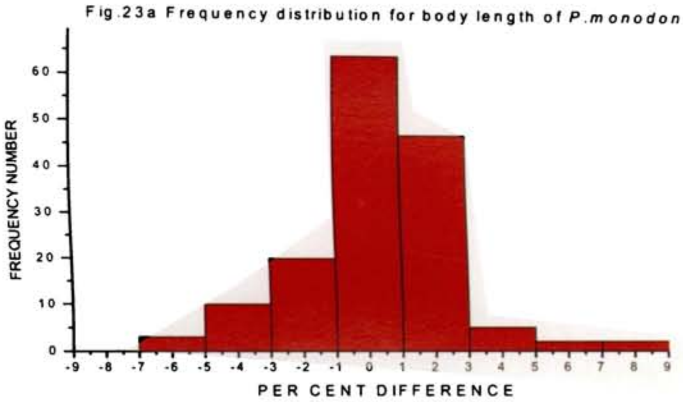


Body length measurements showed that 42 per cent had no difference and 44 per cent showed a 1-3 per cent difference. A difference of 3 to 5 per cent, 5 to 7 per cent and 7 to 9 per cent was shown by 10 per cent, 3 per cent and 1 per cent of measurements respectively (Table23, Fig.23a).

Table 23. Frequency distribution of body length of *P.monodon*

Frequency range (percent)	Frequency (No. of prawns)
+7.0 to + 9.0	2
+5.0 to + 7.0	2
+3.0 to + 5.0	5
+1.0 to + 3.0	47
- 1.0 to + 1.0	64
- 1.0 to - 3.0	20
- 3.0 to - 5.0	10
- 5.0 to - 7.0	3
- 7.0 to - 9.0	0
Total	153

Fig.23a Frequency distribution for body length of *P.monodon*

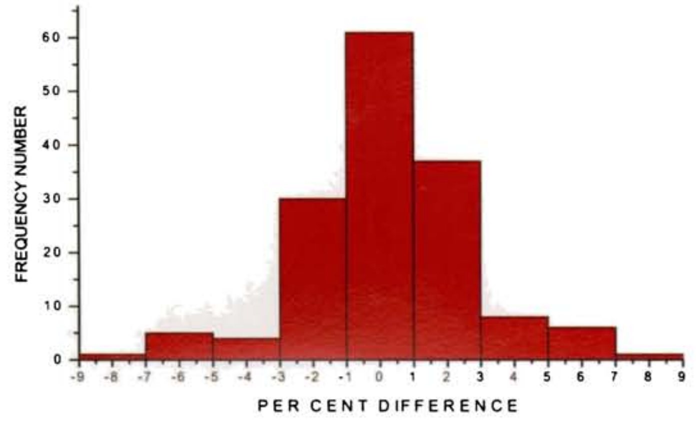


The carapace length measurement on *P. monodon* showed that 40 per cent had no difference and 44 per cent had only an under 3 per cent difference when measured. A difference of 3 to 5 per cent, 5 to 7 per cent and 7 to 9 per cent was shown by 8 per cent, 7 per cent and 1 per cent of the measurements respectively (Table24, Fig.24a).

Table 24. Frequency distribution of carapace length of *P.monodon*

Frequency range (percent)	Frequency (No. of prawns)
+7.0 to + 9.0	1
+5.0 to + 7.0	6
+3.0 to +5.0	8
+1.0 to + 3.0	37
- 1.0 to + 1.0	61
- 1.0 to - 3.0	30
- 3.0 to - 5.0	4
- 5.0 to - 7.0	5
- 7.0 to - 9.0	1
Total	153

Fig.24a Frequency distribution for carapace length of *P.monodon*



4.2 Measurements on coated products

The limitations that image analysis has in quality evaluation research is offset by some of its advantages like the non-destructive nature of the analysis and the absence of the need to handle the product. Hence probing the possibilities in this sector would be always worthwhile. Checking for uniformity of size and dimensions is one such area worth studying.

4.2.1. Measurements on cutlets

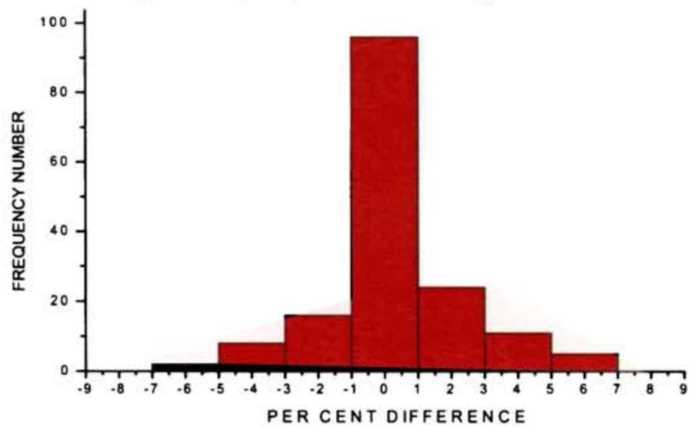
Usually cutlets are shaped oval or round. The present study was carried out on both oval cutlets and round ones. The length and width of the 162 cutlets were measured separately both manually using a graduated ruler and also by image analysis using the analyser software. The difference was computed and represented as frequency distribution to assess accuracy.

While 59 per cent of the cutlets measured for length showed no difference, 25 per cent showed a difference below 3 per cent. The 3 to 5 per cent range was represented by 12 per cent of the readings and only 4 per cent readings showed 5-7 per cent difference for the measurements (Table25, Fig.25a).

Table 25. Frequency distribution of length of cutlet

Frequency range (per cent)	Frequency (No. of cutlets)
+7.0 to + 9.0	0
+5.0 to + 7.0	5
+3.0 to + 5.0	11
+1.0 to + 3.0	24
- 1.0 to + 1.0	96
- 1.0 to - 3.0	16
- 3.0 to - 5.0	8
- 5.0 to - 7.0	2
- 7.0 to - 9.0	0
Total	162

Fig.25a. Frequency distribution for length of cutlets

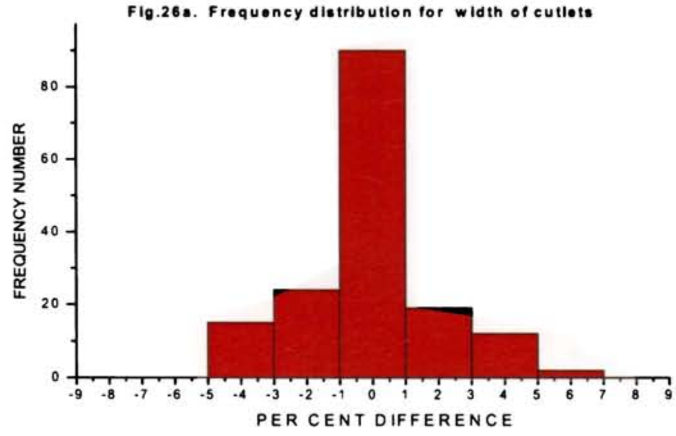


While measuring the width of the same cutlets, 56 per cent showed no difference and 26 per cent showed a difference under 3 per cent. The under 5 per cent and under 7 per cent ranges were represented by 17 per cent and a mere 1 per cent of the measurements (Table26, Fig.26a).

Table 26. Frequency distribution of width of cutlet

Frequency range (per cent)	Frequency (No. of cutlets)
+7.0 to + 9.0	0
+5.0 to + 7.0	2
+3.0 to + 5.0	12
+1.0 to + 3.0	19
- 1.0 to + 1.0	90
- 1.0 to - 3.0	24
- 3.0 to - 5.0	15
- 5.0 to - 7.0	0
- 7.0 to - 9.0	0
Total	162

Fig.26a. Frequency distribution for width of cutlets

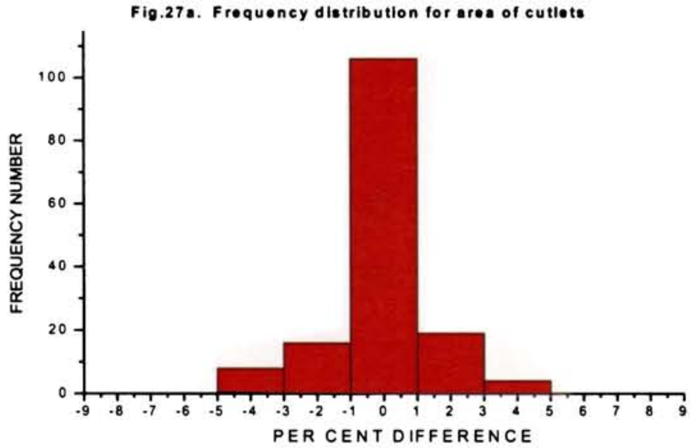


Area was measured on 153 round cutlets, manually computed from diameter and also using the software. While 69 per cent readings showed no difference, 23 per cent showed below 3 per cent and 8 per cent showed 3 to 5 per cent difference (Table27, Fig.27a).

Table 27. Frequency distribution of area of cutlet

Frequency range (per cent)	Frequency (No. of cutlets)
+7.0 to + 9.0	0
+5.0 to + 7.0	0
+3.0 to + 5.0	4
+1.0 to + 3.0	19
- 1.0 to + 1.0	106
- 1.0 to - 3.0	16
- 3.0 to - 5.0	8
- 5.0 to - 7.0	0
- 7.0 to - 9.0	0
Total	153

Fig.27a. Frequency distribution for area of cutlets



4.2.2. Measurements on coating materials

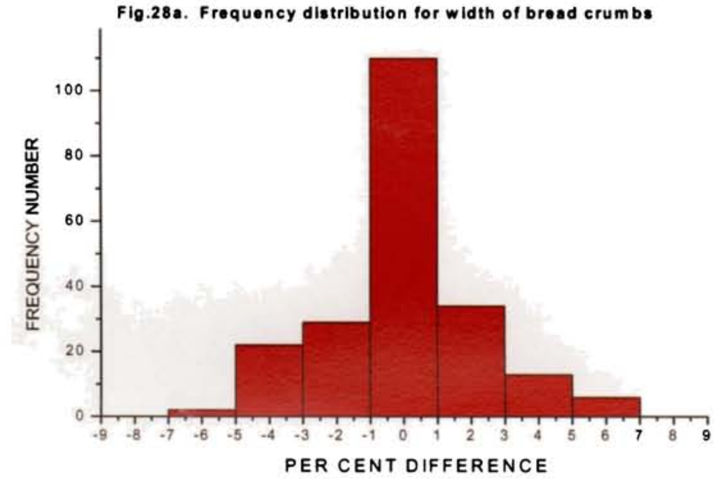
Measurements of bread crumb width showed that 51 per cent of the measurements showed no difference, while 29 per cent showed a difference of under 3 per cent. The 3 to 5 per cent difference was represented by 16 per cent of the measurements while only 4 per cent of the samplings showed 5 to 7 per cent difference (Table28, Fig.28a).

Table28. Frequency distribution of bread crumb width

Frequency range (per cent)	Frequency (No. of particles)
+7.0 to + 9.0	0
+5.0 to + 7.0	6
+3.0 to +5.0	13
+1.0 to + 3.0	34
- 1.0 to + 1.0	110
- 1.0 to - 3.0	29
- 3.0 to - 5.0	22
- 5.0 to - 7.0	2
- 7.0 to - 9.0	0
Total	216

Measurements of rava particle width showed that 56 per cent of the samplings showed no difference. Differences under 3 per cent was shown by 27 per cent of the samplings while 15 per cent and 2 per cent of the samplings

Fig.28a. Frequency distribution for width of bread crumbs

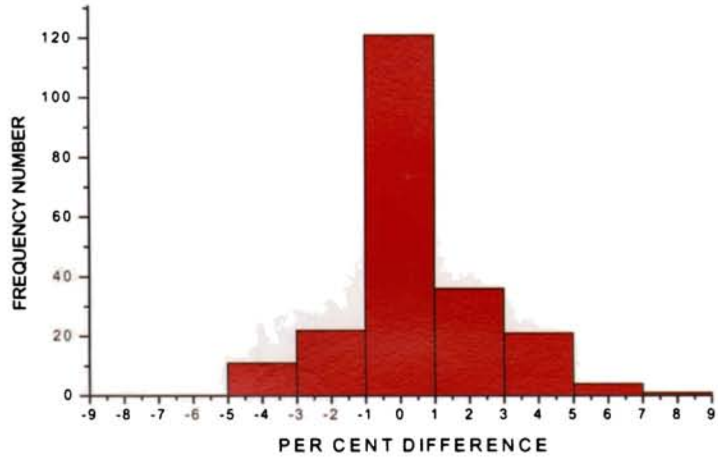


showed 3 to 5 per cent and 5 to 7 per cent difference respectively. A meagre 0.5 per cent of the samplings showed a difference between 7 and 9 per cent (Table29, Fig.29a).

Table29. Frequency distribution of 'rava' width

Frequency range (per cent)	Frequency (No. of particles)
+ 7.0 to + 9.0	1
+5.0 to + 7.0	4
+3.0 to + 5.0	21
+1.0 to + 3.0	36
- 1.0 to + 1.0	121
- 1.0 to - 3.0	22
- 3.0 to - 5.0	11
- 5.0 to - 7.0	0
- 7.0 to - 9.0	0
Total	216

Fig.29a. Frequency distribution for width of rava



4.3. Measurements in bacteriology

In the present study colony counting, measurement of colony diameter and measurement of halo diameter were done both manually and by image analysis. The results were computed for difference and frequency distribution applied for meaningful interpretation of the results.

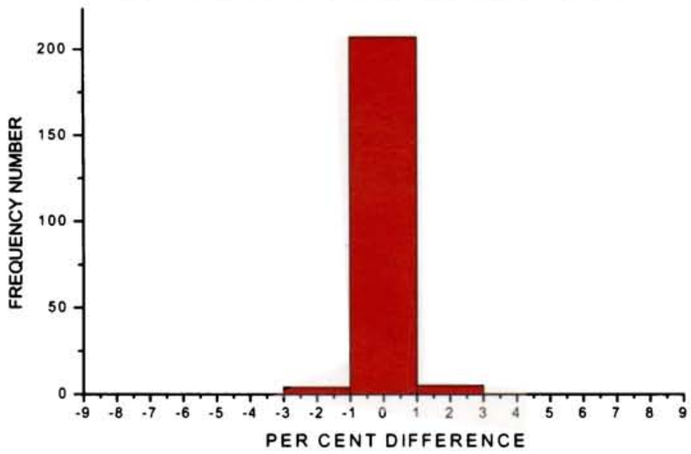
4.3.1. Colony counting

In all, 216 samples of petri plates with colony numbers within the 30 to 300 range were subjected to both manual counting and also counting by image analysis. The results showed that 96 per cent of the measurements had no difference and 4 per cent showed a difference under 3 per cent (Table30, Fig.30a).

Table 30. Frequency distribution of colony counts

Frequency range (per cent)	Frequency (No. of petri plates)
+7.0 to + 9.0	0
+5.0 to + 7.0	0
+3.0 to + 5.0	0
+1.0 to + 3.0	5
- 1.0 to + 1.0	207
- 1.0 to - 3.0	4
- 3.0 to - 5.0	0
- 5.0 to - 7.0	0
- 7.0 to - 9.0	0
Total	216

Fig.30a. Frequency distribution for colony counts of Bacteria



4.3.2. Measurement of colony diameter

Here 144 colonies were selected and marked for measurement. Manual measurement was done under the microscope using an ocular meter which was standardized using a stage micrometer. Same colonies were measured by image analysis, the difference computed and subjected to frequency distribution. Eighty four per cent of the measurements showed no difference, 12.5 per cent showed a difference below 3 per cent and 3.5 per cent had a difference within 3 to 5 per cent (Table31, Fig.31a).

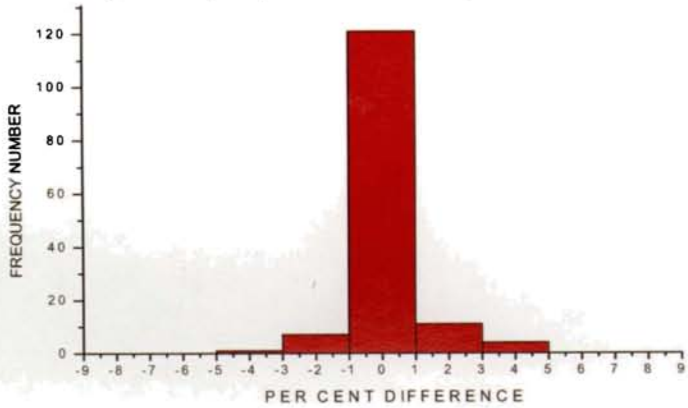
Table 31. Frequency distribution of colony diameter

Frequency range (per cent)	Frequency (No. of colonies)
+7.0 to + 9.0	0
+5.0 to + 7.0	0
+3.0 to + 5.0	4
+1.0 to + 3.0	11
-1.0 to + 1.0	121
-1.0 to -3.0	7
-3.0 to -5.0	1
-5.0 to -7.0	0
-7.0 to -9.0	0
Total	144

4.3.3. Measurement of halo diameter

A total of 270 halos were measured for halo diameter. Manual measurement was done using a scale . Halo diameter of the same halos were also measured by image analysis. The difference was computed and subjected to frequency distribution. Sixty eight per cent of the measurements showed no difference, 22 per cent showed a difference below 3 per cent, 8 per

Fig.31a. Frequency distribution for colony diameter of Bacteria



cent showed a difference below five per cent and only 2 per cent of the entire measurements showed a differences between 5and 7 per cent. This is highlighted in the following table and figure (Table32, Fig.32a).

Table 32. Frequency distribution of halo diameter

Frequency range (per cent)	Frequency (No. of halos)
+7.0 to + 9.0	0
+5.0 to + 7.0	4
+3.0 to +5.0	12
+1.0 to + 3.0	31
-1.0 to + 1.0	183
-1.0 to -3.0	28
-3.0 to -5.0	10
-5.0 to -7.0	2
-7.0 to -9.0	0
Total	270

Fig.32a. Frequency distribution for Halo diameter of Bacterial colonies

4.4. Modelling for shrimp weight determination

The shrimps were categorised into three lots and designated as large, medium and small based on their processed weight. All individual pieces of beheaded, peeled, and cooked prawn with a processed weight of 10 g and above per piece were designated as LARGE, those with processed weight 4-10 g as MEDIUM and those with processed weight 4 g and less as SMALL. There were twenty four specimens each in large and medium categories and thirty in the small category.

4.4.1. Model for large shrimp

For each individual specimen, diameter was measured by computer vision using the image analyser software. In each case ten measurements were made and their average was computed. The weight of individual pieces was accurately taken. The relevant statistical measures were computed and are given in Table33.

Table 33. Summary statistics of large shrimp *(F. indicus)*

	n	Range	Mean	S.D	S.E.
Weight(g)	24		18.11	4.27	0.87
Diameter(cm)	24	3.43 – 4.68	4.09	0.35	0.07

While the weight ranged from 10.01g - 23.94g with a mean of 18.11g, the diameter varied between 3.43cm and 4.68cm with a mean of 4.09cm.The data on diameter and weight of the twenty four specimen depict a linear relationship. Hence a simple linear regression equation was fitted to the data. Diameter (D)was taken as the independent variable and weight (W) as the dependent variable. The results of regression analysis are presented in Tables 34 and 35.

The very low probability (P) values in the tables clearly indicate a very strong linear relationship between diameter and weight. The derived regression model is given by the equation :

$$W = 11.6352\,D - 29.53$$

This model provided a good fit to the sample data as evidenced by a higher value of Coefficients of determination (R^2 = 93.11%) and a low standard error of the estimate (S.E. = 1.1465). It could be used for determining the weight in grams of large sized prawns knowing their diameter accurately measured in centimetres. This model is named **KRIMSNON 1 Model**, after the author's names in abbreviated form.

Table 34. Regression anova of large shrimp (*F.indicus*) (n = 24)

sources of variation	df	S.S.	M.S.	F	P
Regression	1	390.62	390.62	297.17	2.9 E -14
Residual	22	28.92	1.31		
Total	23	419.54			

Table 35. Summary of regression output of large shrimp (n =24)

	Coft.	S.E	t value	P - value	R^2 (%)	S.E. of estimate
Intercept	-29.53	2.7735	-10.65	3.81 E -10	93.11	1.1465
Indcpen-dent variable	11.6352	0.6750	17.24	2.90 E -14		

4.4.2. Model for medium shrimp

For every individual "medium" category specimen the diameter was measured by computer vision with the image analyser software. In each case 10 measurements were made and their average was computed. The weight of individual pieces was accurately taken using an electronic digital balance.

While the weight ranged from the 5.25 g for the smallest and 9.18 g for the largest piece with a mean of 7.20 g the diameter measurements in real scale showed values of 2.72 cm and 3.55 cm for the smallest and largest specimens respectively with a mean of 3.07 cm. The statistics for the specimen designated as 'medium' are given in Table36.

Table 36. Summary statistics of medium shrimp (*F. indicus*)

	Sample Size (n)	Range	Mean	S.D.	S.E.
Weight (g)	24	5.25 – 9.18	7.20	1.28	0.26
Diameter (cm)	24	2.72 – 3.55	3.07	0.23	0.047

While standard deviation was 1.28 for the weights it was only 0.23 for the diameter readings and standard error was 0.26 for weights and 0.047 for diameter readings. The data on diameter and weight of the 24 specimen depict a linear relationship. Hence a simple linear regression equation was fitted to the data. Diameter (D) was taken as the independent variable and weight (W) as the dependent variable. The results of regression analysis are presented in Tables 37 and 38.

Table 37. Regression Anova of medium shrimp (*F.indicus*) (n = 24)

Sources of variation	df	S.S	M.S	F	P
Regression	1	32.92	32.92	156.26	1.81×10^{-11}
Error	22	4.63	0.21		
Total	23	37.55			

Table 38. Summary of regression output of medium shrimp (n = 24)

	Coft.	S.E	t value	P value	R^2 (%)	S.E of estimate
Intercept	-8.7587	1.2804	-6.84	7.16 E – 07	87.65	0.4590
Independent Variable	5.1941	0.4155	12.50	1.81 E - 11		

The very low probability (P) values in the tables clearly indicate a very strong linear relationship between diameter and weight. The derived regression model is given by the equation

W = 5.19 D – 8.76

The model provided a good fit to the sample data as evidenced by a higher value of coefficient of determination (R = 87.65 %) and a low standard error of the estimate (S.E = 0.4590). It could be used for determining the weight in grams of "medium" sized prawns knowing their diameter accurately measured in centimetres. This model is named **KRIMSNON 2 Model**, after the authors' names in abbreviated form.

4.4.3. Model for small shrimp

For every individual specimen within the "small" category, the diameter was measured by computer vision using the image analyser software. In each case ten measurements were made and their average was computed. The weight of individual pieces was accurately taken using an electronic digital balance. The relevant statistical measures were computed and given in Table 39.

Table 39. Summary statistics of small shrimp (*F. indicus*)

	Sample Size (n)	Range	Mean	S.D.	S.E.
Weight (g)	30	0.90 – 4.01	2.4953	0.9530	0.1740
Diameter (cm)	30	1.23 – 2.76	2.0223	0.5290	0.0966

The weight range for the small specimen varied between 0.9 g for the smallest and 4.01 g for the largest piece with a mean of 2.4953 g, while the diameter measurements in real scale showed values of 1.23 cm and 2.76 cm for the smallest and largest specimen respectively with a mean of 2.0223 cm.

While the standard deviation was 0.9530 for the weights it was 0.5290 for the diameter readings and standard error was 0.174 for weights and 0.0966 for diameter. The data on the diameter and weight of the 30 specimen depict a linear relationship. Hence a simple linear regression equation was fitted to the data. Diameter (D) was taken as the independent variable and weight (W) as the dependent variable. The results of regression analysis are presented in Tables 40 and 41.

Table 40. Regression anova of small shrimp (*F.indicus*) (n=30)

Sources of variation	df	S.S	M.S	F Ratio	P
Regression	1	25.23	25.28	635.55	$8.65X10^{-21}$
Residual	28	1.11	0.04		
Total	29	26.34			

Table 41. Summary of regression output of small shrimp (n=30)

	Coft.	S.E	t value	P value	R^2 (%)	S.E. of estimate
Intercept	-1.0702	0.1460	-7.33	5.58 E - 08	95.78%	0.1992
Independent variable	1.7631	0.0699	25.21	8.65 E - 21		

The very low probability (P) values in the tables clearly indicate a very strong linear relationship between diameter and weight. The derived regression model is given by the equation

$$\mathbf{W = 1.76\ D - 1.07}$$

The model provided a good fit to the sample data as evidenced by a higher value of Coefficient of determination (R = 95.78 %) and a low Standard Error of the estimate (S.E = 0.1992). This could be used for determining the weight in grams of " small" sized prawns knowing their diameter accurately measured in centimetres. This model is named **KRIMSNON 3 Model**, after the authors' names in abbreviated form.

The relationship between diameter (D) and weight (W) of small sized shrimp (*F.indicus*) is also given in the figures (Fig.33 to 36).

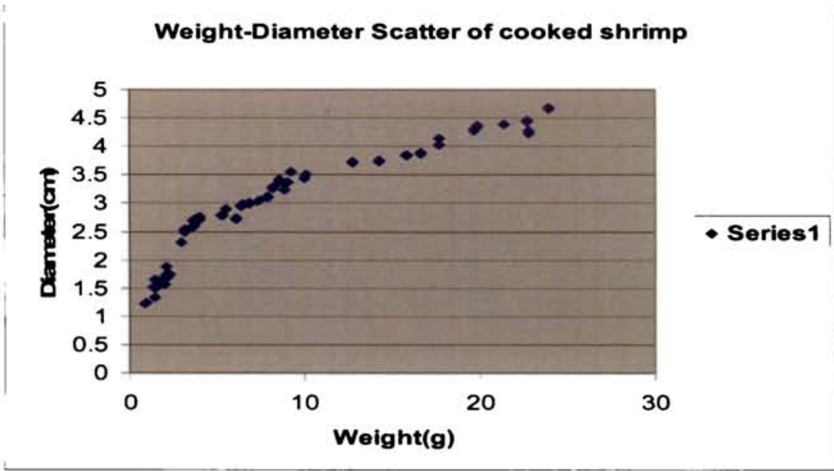


Fig. 33 Scatter diagram of entire data (average values) of all prawns

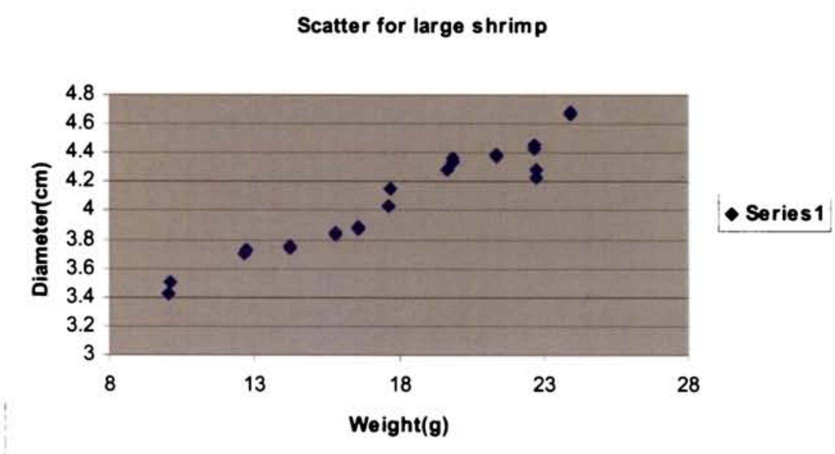


Fig.34. Scatter diagram of large shrimp

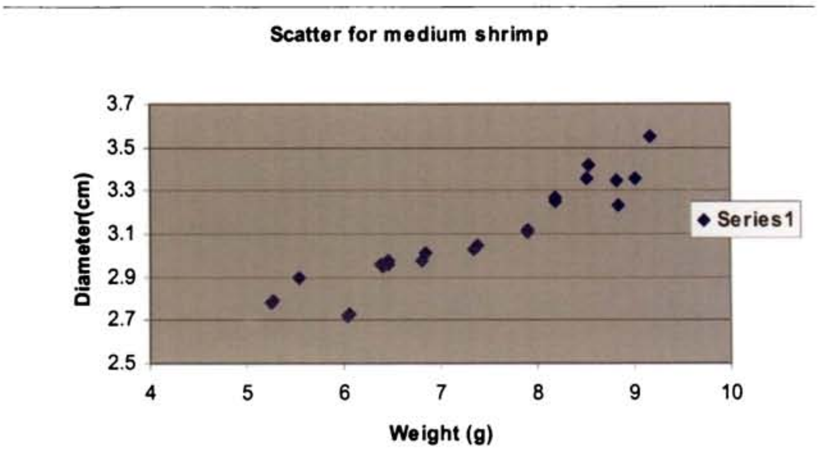


Fig.35. Scatter diagram of medium shrimp

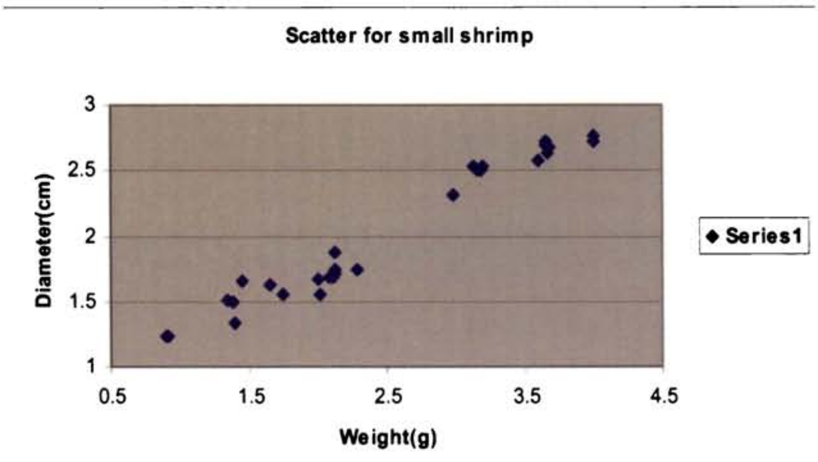


Fig. 36. Scatter diagram of small shrimp

4.4.4. Audit and Verification

The audit and verification carried out on entirely new 3 sets of samples grouped into three different categories of small, medium and large showed results on expected lines. In the case of small shrimps, correlation coefficient between calculated values and measured values was found to be 0.90 showing that the model for small shrimp was quite dependable in predicting or estimating the weight of any individual shrimp from its image. In the case of medium sized shrimp, the correlation coefficient was 0.87 and in the case of large sized shrimp the correlation coefficient showed a value of 0.89, these also showing reliability in the prediction of weight.

5. DISCUSSION

The experimental work comprised of a variety of comparative evaluations between existing conventional techniques of quality related measurements and computer vision cum software based measurement techniques. Attempts have been made here at testing the accuracy of the software based image analysis techniques to ascertain whether image analysis based measurements could replace some of the conventional ones. The extent of success of such image analysis techniques have been discussed here item by item.

Every morphometric measurement on nine different lengths in both Mackerels and Sardines using the existing conventional manual method as compared to an image analysis technique showed remarkable closeness between the values obtained. Difference between manual measurements and image analysis based measurements were recorded as zero difference / positive difference / negative difference as the case may be and frequency distribution calculated. A normal frequency distribution curve was observed in all cases.

The total length, fork length and standard length (Tables 42-44)

Table 42. Morphometrics on Mackerel: Total length

Class Intervals	Frequency(percent)	Cumulative
0 difference	51	51
< 3% difference	31	82
<5% difference	14	96
<7% difference	4	100
<9% difference	0	100
Total	100	100

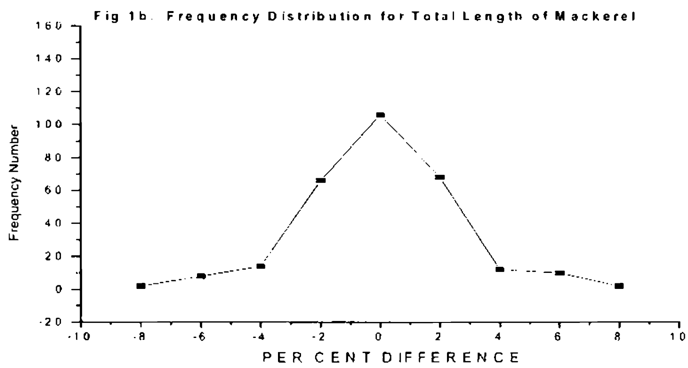
Table 43. Morphometrics on Mackerel: Fork length

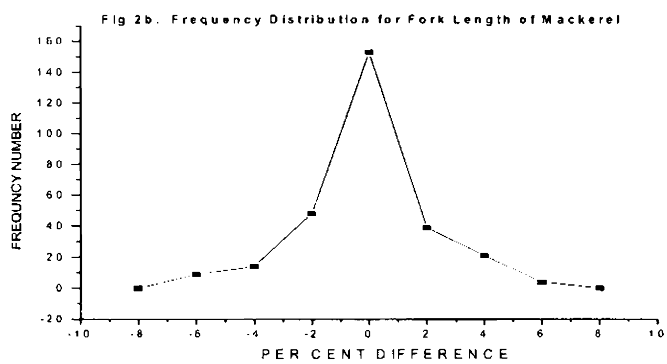
Class Intervals	Frequency(percent)	Cumulative
0 difference	53	53
< 3% difference	30	83
<5% difference	12	95
<7% difference	4.5	99.5
<9% difference	0	99.5
Total	100	99.5

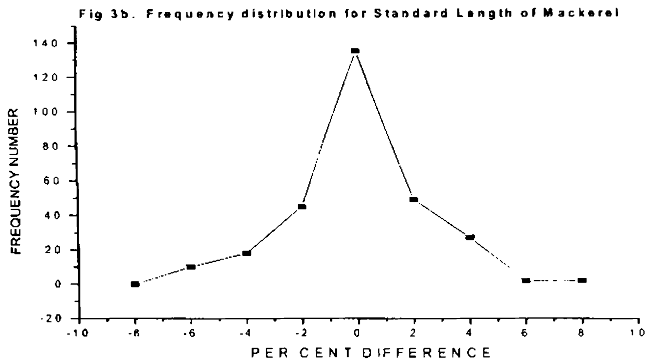
Table 44. Morphometrics on Mackerel:Standard length

Class Intervals	Frequency (percent)	Cumulative
0 difference	47	47
< 3% difference	33	80
<5% difference	16	96
<7% difference	4	100
<9% difference	0.7	100.7
Total	100.7	100.7

showed that nearly 50 per cent of the measurements had no difference and another 30 per cent showed under 3 per cent difference. The 3 to 5 per cent difference was represented by another 15 per cent of the data. Thus roughly 95 per cent of all the measurements fell within a 5 per cent margin of difference. The graphs representing these 3 sets of measurements showed very similar trends and were well within comparable limits in Mackerels (Figs.1b, 2b and 3b) .







A similar pattern was exhibited by the other six morphometric measurements namely body depth, snout length, eye diameter, post orbital length, head length and caudal peduncle length (Tables 45-50).

Table 45. Morphometrics on Mackerel: Body depth.

Class Intervals	Frequency (per cent)	Cumulative
0 difference	38	38
< 3% difference	35	73
<5% difference	19	92
<7% difference	6	98
<9% difference	2	100
Total	100	100

In all cases it was noticed that a zero difference was shown by 30 to 40 per cent of the measurements while a total of 70 to 85 per cent of the measurements had an under 3 per cent difference. In all, an under 5 per cent

Table 46. Morphometrics on Mackerel: Snout length

Class Intervals	Frequency (per cent)	Cumulative
0 difference	30	30
< 3% difference	52	82
<5% difference	11	93
<7% difference	6	99
<9% difference	1	100
Total	100	100

Table 47. Morphometrics on Mackerel: Eye diameter.

Class Intervals	Frequency (per cent)	Cumulative
0 difference	34	34
< 3% difference	38	72
<5% difference	18.5	90.5
<7% difference	10	100.5
<9% difference	0	100.5
Total	100.5	100.5

Table 48. Morphometrics on Mackerel: Post orbital.

Class Intervals	Frequency (per cent)	Cumulative
0 difference	37	37
< 3% difference	47	84
<5% difference	9	93
<7% difference	6	99
<9% difference	1.4	100.4
Total	100.4	100.4

Table 49. Morphometrics on Mackerel: Head length.

Class Intervals	Frequency (per cent)	Cumulative
0 difference	35	35
< 3% difference	48	83
<5% difference	11.5	94.5
<7% difference	5.5	100
<9% difference	0	100
Total	100	100

Table 50. Morphometrics on Mackerel: Caudal peduncle.

Class Intervals	Frequency(per cent)	Cumulative
0 difference	31	31
< 3% difference	39	70
<5% difference	23	93
<7% difference	5	98
<9% difference	3	101
Total	101	101

difference was shown by nearly 90 to 95 per cent of the measurements (Figs.4b, 5b, 6b, 7b, 8b and 9b). All these observations showed good agreement with the results reported by Arnarson (1991) who carried out similar measurements, both manual and digital, on cod fish meant for deheading and filleting.

Fig 4b. Frequency distribution for body depth of Mackerel

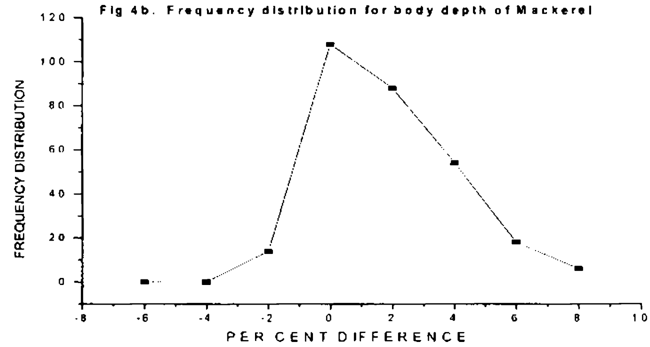


Fig 5b. Frequency distribution for snout length of Mackerel

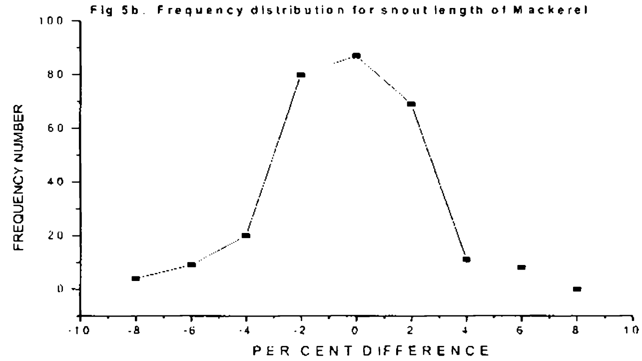
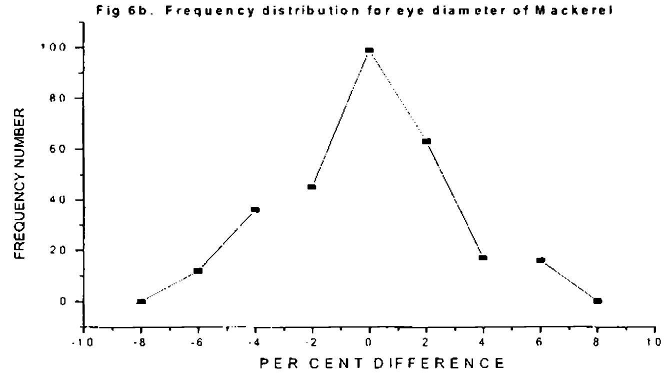


Fig 6b. Frequency distribution for eye diameter of Mackerel



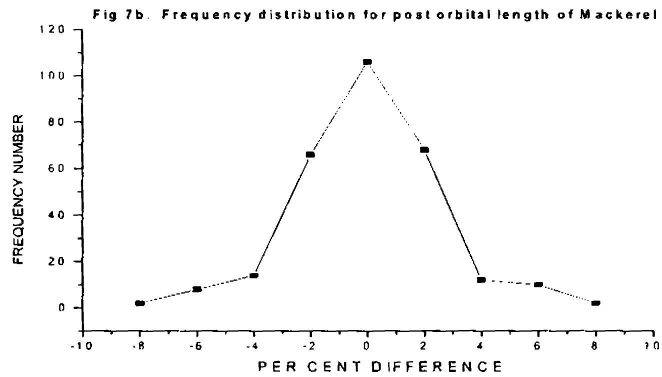


Fig 7b. Frequency distribution for post orbital length of Mackerel
FREQUENCY NUMBER
PER CENT DIFFERENCE

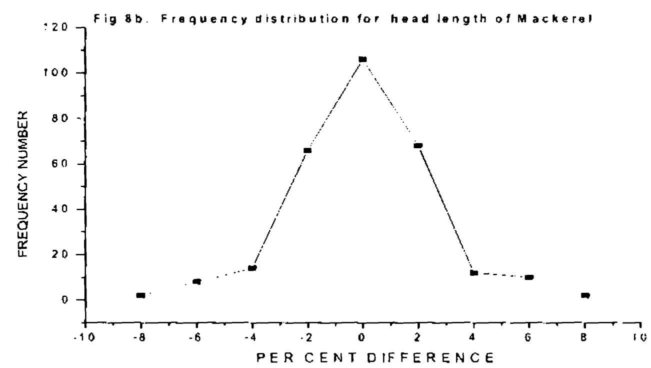


Fig 8b. Frequency distribution for head length of Mackerel
FREQUENCY NUMBER
PER CENT DIFFERENCE

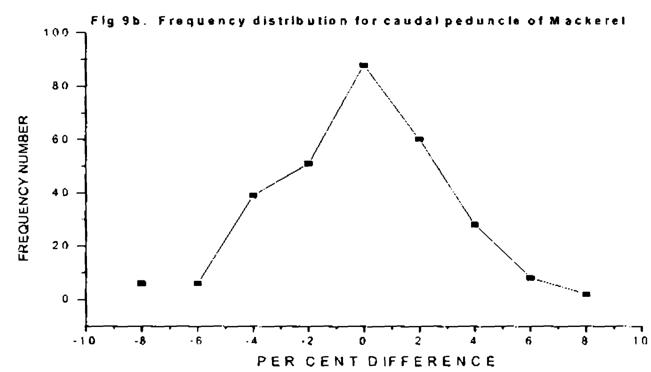


Fig 9b. Frequency distribution for caudal peduncle of Mackerel
FREQUENCY NUMBER
PER CENT DIFFERENCE

The results obtained in the case of morphometric measurements on Sardines were no different from that obtained in the case of Mackerels. The first three length measurements namely the total length, the fork length and the standard length as seen from the data on Tables 51-53 showed that 50 to 55

Table 51. Morphometrics on Sardines: Total length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	54	54
< 3% difference	25	79
<5% difference	12	91
<7% difference	7.5	98.5
<9% difference	2	100.5
Total	100.5	100.5

Table 52. Morphometrics on Sardines: Fork length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	51	51
< 3% difference	32	83
<5% difference	11	94
<7% difference	6	100
<9% difference	1	101
Total	101	101

Table 53. Morphometrics on Sardines: Standard length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	50	50
< 3% difference	34	84
<5% difference	12	96
<7% difference	4	100
<9% difference	0	100
Total	100	100

per cent of the measurements had no difference between the manual method of measurement and the image analysis route of measurement, while 80 to 85 per cent of the readings showed a difference under 3 per cent and 91 to 96 per cent of the recording (Figs.10b,11b, and 12b) had only a difference under 5 per cent. The

Fig 10b. Frequency distribution for total length of Sardine

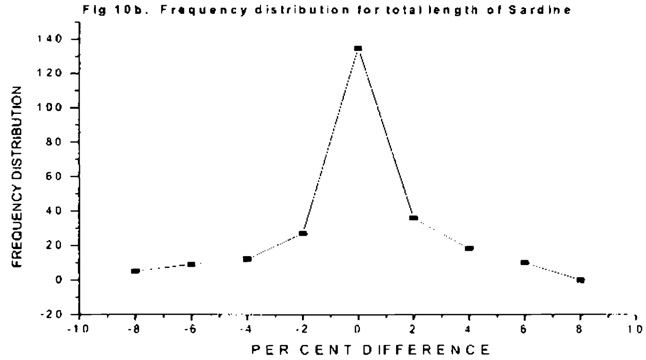


Fig 11b. Frequency distribution for fork length ofSardine

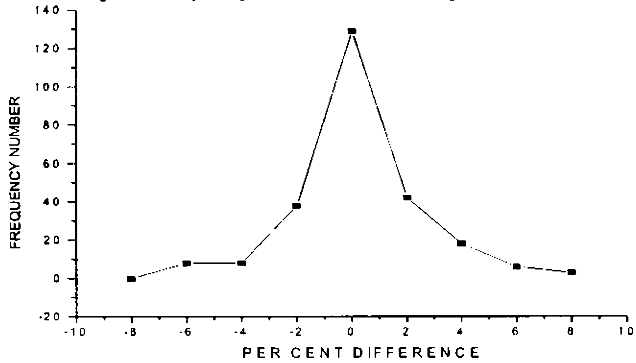


Fig.12b. Frequency distribution for standard length ofSardine

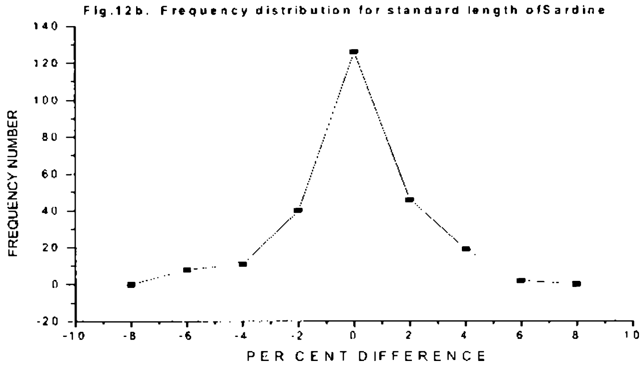


Table 54. Morphometrics on Sardines: Body depth.

Class Intervals	Frequency in(percent)	Cumulative
0 difference	40	40
< 3% difference	37	77
<5% difference	18	95
<7% difference	4	99
<9% difference	1	100
Total	100	100

other shorter morphometric lengths measured namely the body depth, the snout length, the eye diameter, the post orbital length, the head length and the caudal peduncle length using both measurement techniques(Tables 54-59)

Table 55. Morphometrics on Sardines: Snout length.

Class Intervals	Frequency (percent)	Cumulative
0 difference	34	34
< 3% difference	51	85
<5% difference	10	95
<7% difference	4	99
<9% difference	1	100
Total	100	100

Table 56. Morphometrics on Sardines: Eye diameter.

Class Intervals	Frequency (percent)	Cumulative
0 difference	38	38
< 3% difference	36	74
<5% difference	14	88
<7% difference	12	100
<9% difference	0	100
Total	100	100

Table 57. Morphometrics on Sardines: Post orbital length.

Class Intervals	Frequency (percent)	Cumulative
0 difference	42	42
< 3% difference	41	83
<5% difference	11	94
<7% difference	5	99
<9% difference	0.8	99.8
Total	99.8	99.8

Table 58. Morphometrics on Sardines: Head length.

Class Intervals	Frequency (percent)	Cumulative
0 difference	38	38
< 3% difference	42	80
<5% difference	16	96
<7% difference	4	100
<9% difference	0	100
Total	100	100

Table 59. Morphometrics on Sardines: Caudal peduncle height.

Class Intervals	Frequency (percent)	Cumulative
0 difference	34	34
< 3% difference	35	69
<5% difference	20	89
<7% difference	8	97
<9% difference	3	100
Total	100	100

showed similar and comparable results. The results were almost identical to those obtained in the case of Mackerel. While 35 to 45 per cent of the measurements had no difference, nearly 70 to 85 per cent of the readings had only a difference under 3 per cent and nearly 88 to 96 per cent of the observations had only a difference of under 5 per cent (Figs.13b, 14b, 15b, 16b, 17b and 18b).These results too are in good agreement with the results on the measurement of length in cod reported by Arnarson (1991).

Fig.13b. Frequency distribution for body depth ofSardine

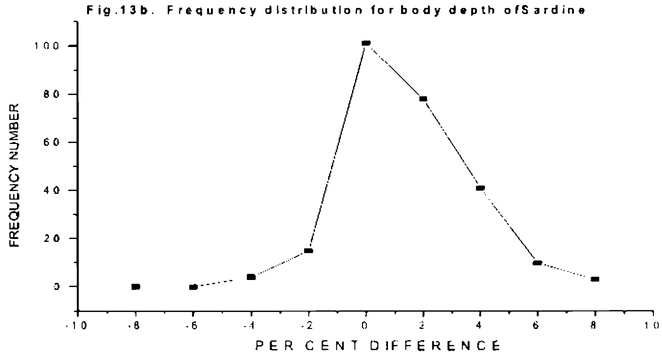


Fig.14b. Frequency distribution for snout length ofSardine

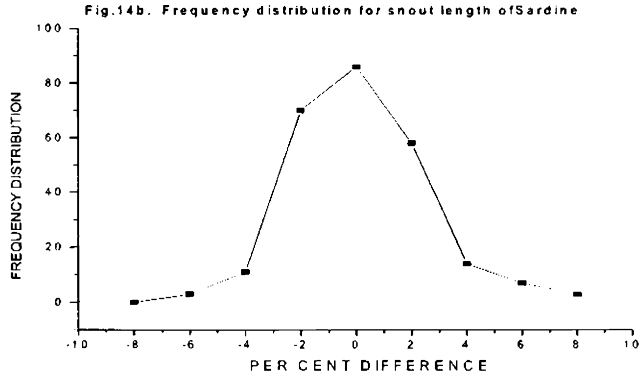


Fig.15b. Frequency distribution for eye diameter ofSardine

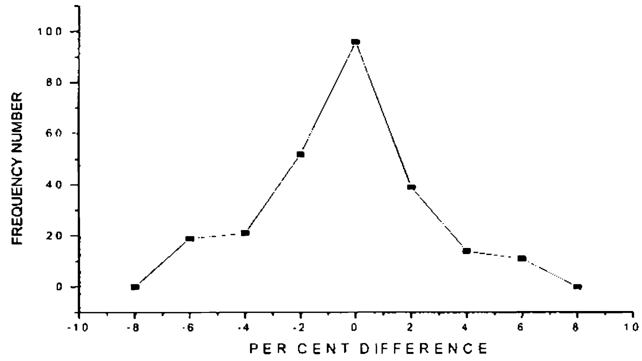


Fig.16b. Frequency distribution for post orbital length ofSardine

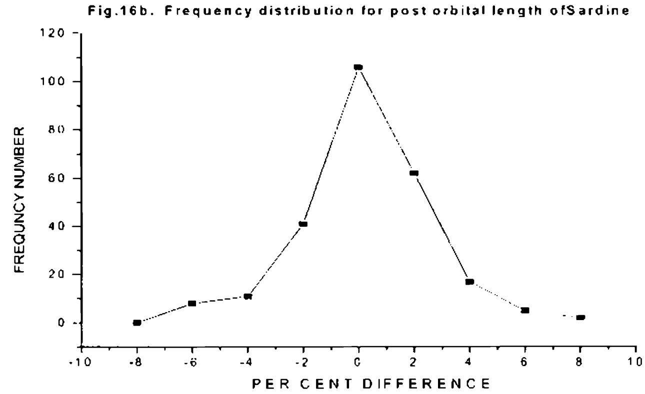
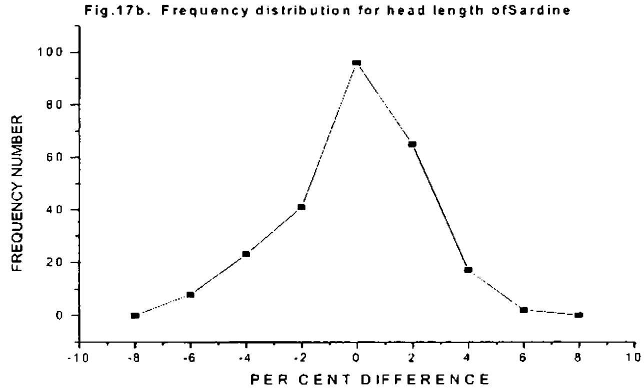
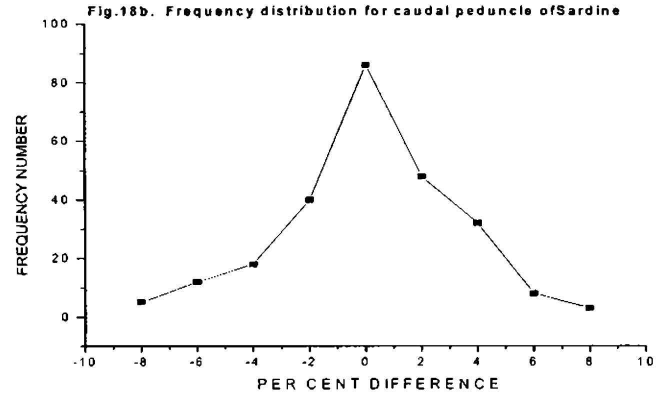


Fig.17b. Frequency distribution for head length ofSardine





In the case of short length measurements such as snout length, eye diameter and caudal peduncle length, the spread was found wider with a higher percentage representation in the 1 to 3 per cent difference range and the 3 to 5 per cent difference range in comparison with the differences shown by the other six measurements such as total length, fork length, standard length, body depth, head length and post orbital length. The body depth measurement differences showed a definite skew towards a positive difference for the image analysis measurements suggesting that probably dividers when used for manual measurements could have pressed on to the soft bellies resulting in a constant lower reading than the software based measurements.

While carrying out morphometric measurements on prawns, the three lengths measured were total length, body length and carapace length on both *F. indicus* (Tables 60-62) and *P. monodon* (Tables 63-65).

Table 60. Morphometrics on Prawns (*F. indicus*): Total length.

Class Intervals	Frequency(Percent)	Cumulative
0 difference	40	40
< 3% difference	42	82
<5% difference	9	91
<7% difference	6	97
<9% difference	3	100
Total	100	100

Table 61. Morphometrics on Prawns (*F. indicus*): Body length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	43	43
< 3% difference	41	84
<5% difference	7	91
<7% difference	7	98
<9% difference	2	100
Total	100	100

Table 62. Morphometrics on Prawns (*F. indicus*): Carapace length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	39	39
< 3% difference	43	82
<5% difference	10	92
<7% difference	5	97
<9% difference	3	100
Total	100	100

Table 63. Morphometrics on Prawns (*P. monodon*): Total length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	41	41
< 3% difference	40	81
<5% difference	9	90
<7% difference	8	98
<9% difference	2	100
Total	100	100

Table 64. Morphometrics on Prawns (*P. monodon*): Body length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	42	42
< 3% difference	44	86
<5% difference	10	96
<7% difference	3	99
<9% difference	1	100
Total	100	100

Table 65. Morphometrics on Prawns (*P.monodon*): Carapace length.

Class Intervals	Frequency(percent)	Cumulative
0 difference	40	40
< 3% difference	44	84
<5% difference	8	92
<7% difference	7	99
<9% difference	1	100
Total	100	100

Nearly 40 to 45 per cent of all the measurements of TL, BL and CL in the case of both species were found to have practically no difference between the conventional manual measurements and the experimental computer vision cum software based measurements. In all cases it was found that nearly 80 to 86 per cent of the measurements had only under 3 per cent difference and close to 96 per cent of the measurements showed only a difference under 5 per cent (Figs.19b, 20b, 21b, 22b, 23b and 24b). The reliability in application of the new experimental computer vision cum software based technique in morphometrics seemed quite evident. The results obtained were very well in consonance with the results and inference reported by Arnarson(1991) in his studies on morphometric length measurements in cod fish for the purpose of sorting before feeding them to decapitating and /or filleting machines.

Fig 19b. Frequency distribution for total length of *F. indicus*

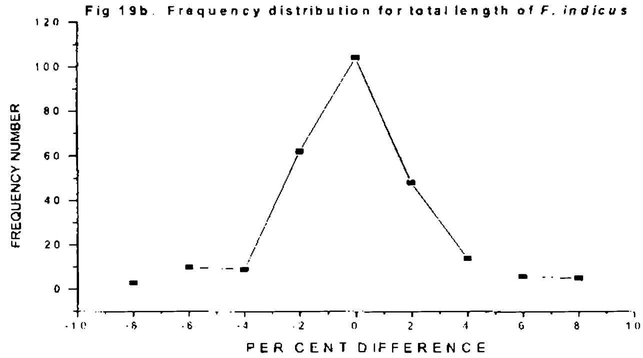


Fig 20b. Frequency distribution for body length of *F. indicus*

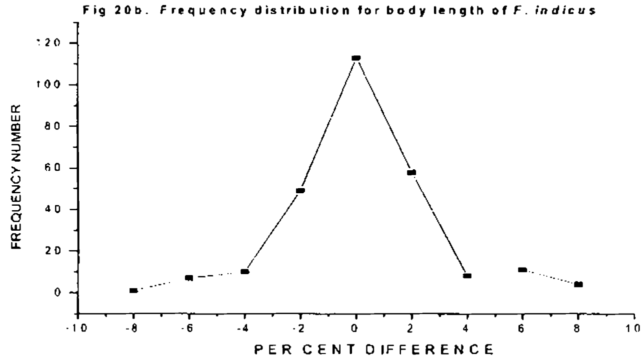


Fig 21b. Frequency distribution for carapace length of *F. indicus*

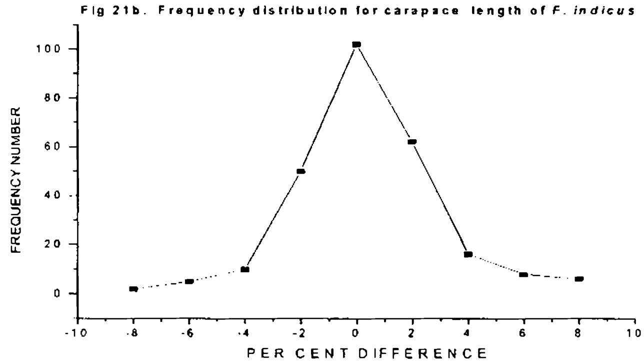


Fig.22b Frequency distribution for total length of *P. monodon*

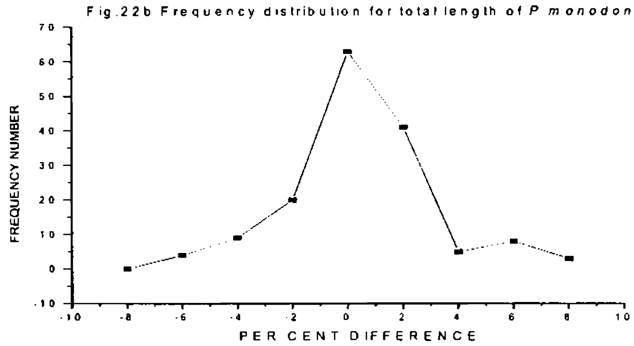


Fig.23b Frequency ditribution for body length of *P.monodon*

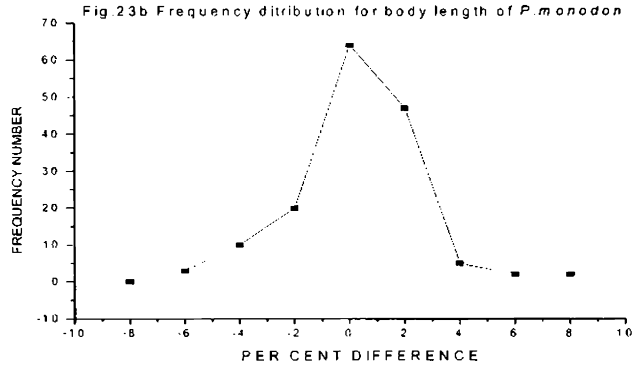
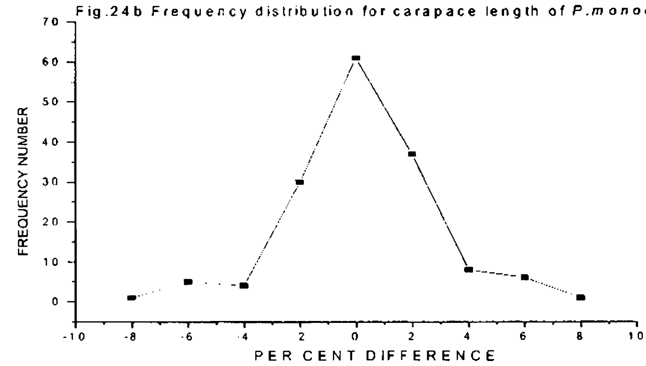


Fig.24b Frequency distribution for carapace length of *P.monodon*



Dunbrack (2006) carrying out fish body length measurements using in –situ measurement techniques based on photographic / video image analysis found lengths of PVC pipes under water and in air when compared to differ by an average difference of only 1.6 per cent. Replicate length measurements conducted by him on free-swimming Bluntnose six gill sharks *Hexacanthus griseus* also differed by an average difference of only 1.6 per cent. Neave *et al.* (2006) while studying the effects of preservation by formalin or alcohol on length variations of preserved specimen for biological studies applied image analysis based length measurements on the specimen samples for six standard morphometric length measurements and ten areas of pigmentation. These were measured and analysed by multiple measurements over time and the results subjected to regression analysis so that the regression equations could allow for accurate correction of preservation effects on morphometrics. White *et al.* (2006) doing automated measurement of length of fish by computer vision using an automatic equipment called "The Catchmeter" found that image processing and image analysis technique could measure the length of every specimen with a standard deviation of a mere 1.2 mm. Imai and Yamamot(2007) applied a method for measuring the body length of landed fish using an image analysis technique. Fork length measurements by the application of image analysis was successfully carried out on Yellow sea bream (*Dentex tumifrous*) landed at the Shimonoseki port fish wholesale market. In total 2938 individuals were measured from 367 images with two correcting functions applied for neutralizing the bent positions of the fish inside containers / fish boxes.

Image analysis application in measuring the length and width of cutlets and the area of cutlets showed promise here. For length and width a scale / ruler was used in the case of manual measurements. Area was manually measured by taking the outline on a graph sheet and counting the number of squares in the case of elliptically shaped cutlets. In the case of round cutlets, the area was computed mathematically from the diameter using the formula method. The results of length and width measurements (Tables 66 & 67) showed

Table 66. Measurements on cutlets: Length of cutlets.

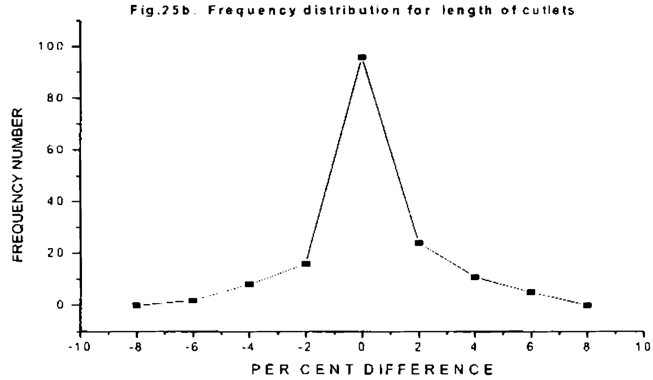
Class Intervals	Frequency (percent)	Cumulative
0 difference	59	59
< 3% difference	25	84
<5% difference	12	96
<7% difference	4	100
<9% difference	0	100
Total	100	100

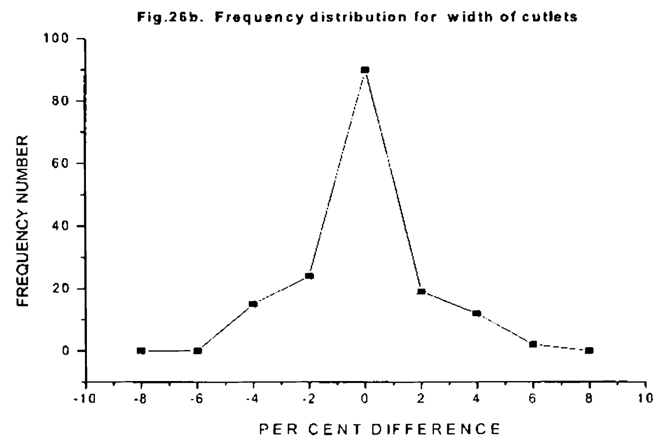
Table 67. Measurements on cutlets: Width of cutlets.

Class Intervals	Frequency(percent)	Cumulative
0 difference	56	56
< 3% difference	26	82
<5% difference	17	99
<7% difference	1	100
<9% difference	0	100
Total	100	100

that 55 to 60 per cent of the measurements had no difference, nearly 82 to 84 per cent of the measurements showed a difference under 3 per cent. While 96 per cent of the length measurements had less than 5 per cent variation, the width measurements showed that 99 per cent of the data was well within a 5 per cent difference (Figs.25b and 26b).

Fig.25b. Frequency distribution for length of cutlets





Area measurements displayed no difference for 69 per cent of the data, while 92 per cent of the data showed under 3 per cent and all the measurements had a variation (Fig.27b) well within 5 per cent (Table 68).

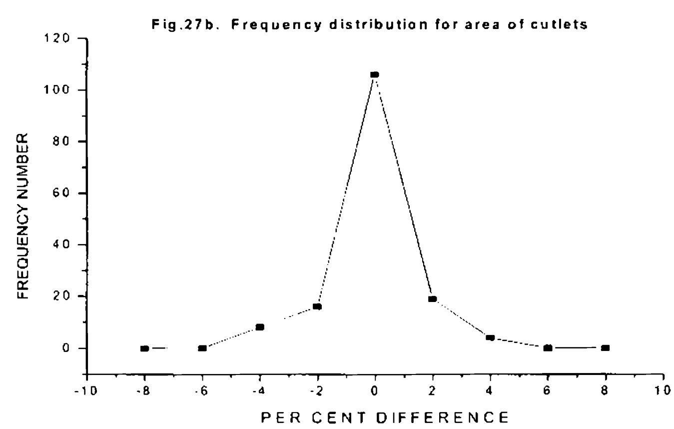


Table 68. Measurements on cutlets: Area of cutlets.

Class Intervals	Frequency(percent)	Cumulative
0 difference	69	69
< 3% difference	23	92
<5% difference	8	100
<7% difference	0	100
<9% difference	0	100
Total	100	100

Measurements of width or diameter of coating materials such as bread crumbs and rava showed that 50 to 56 per cent of measurements had no difference, 83 per cent showed less than 3 per cent difference and 98 per cent of the measurements(Fig.28b, 29b) showed less than 5 per cent difference (Table 69 and 70).

Fig.28b. Frequency distribution for width of bread crumbs

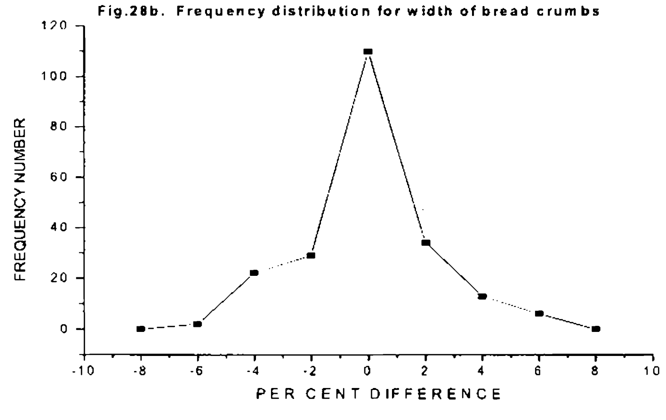


Fig.29b. Frequency distribution for width of Rava

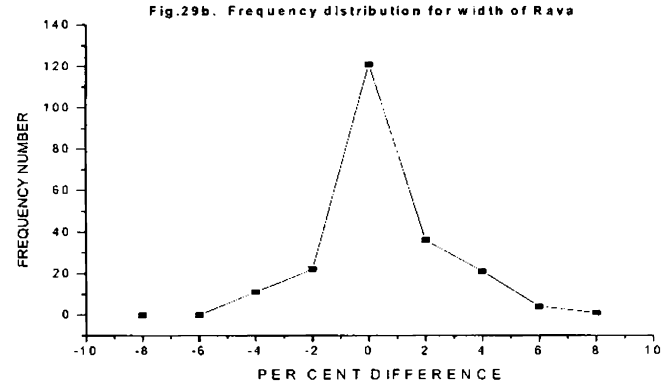


Table 69. Measurements on coating materials: Bread crumbs.

Class Intervals	Frequency(percent)	Cumulative
0 difference	51	51
< 3% difference	29	80
<5% difference	16	96
<7% difference	4	100
<9% difference	0	100
Total	100	100

Table 70. Measurements on coating materials: Rava.

Class Intervals	Frequency(percent)	Cumulative
0 difference	56	56
< 3% difference	27	83
<5% difference	15	98
<7% difference	2	100
<9% difference	0.5	100.5
Total	100.5	100.5

Misimi *et al.* (2008) successfully carried out computer vision based evaluation of pre and post rigor changes in the size and shape of Atlantic cod (*Gadus marhua*) and Atlantic salmon (*Salmo salar*) fillets by measuring length, width, height, area and roundness. As far as measurements on products are concerned Kiessling *et al.* (2006) applied four different techniques to whole fillet contraction (WFC) as percentage shrinkage using an automatic image analyzer. The effect of pre-mortem and post- mortem temperature on rigor was studied by relating percentage shrinkage to it. The shrinkage was measured successfully using image analysis. Roth *et al.* (2007) studied the effect of exsanguinations on fillet quality. The study was carried out sensorily, mechanically and by image analysis. They went on to state that while mechanical analysis using puncture test or shear force could not detect any difference and so also the taste panel, there was a difference visually and image analysis could quantify this on fillets. Misimi *et al.* (2008) studying the size and shape of the Atlantic cod (*G. morhua*) and the Atlantic Salmon (*S. salar*) fillets during rigor mortis and iced storage used image analysis for measuring the length, width, area, roundness and height of the stressed and unstressed fillets. According to them the image analysis route was very effective and dependable for this purpose and can be used for grading the fillets according to uniformity in size and shape as well as measurement of fillet yield measured in thickness. The methods were accurate, rapid, non-destructive and contact-free.

Colony counting applying image analysis verses number of colonies counted on the plates using a Quebec colony counter showed that 96 per cent of the counted samples showed no difference. Further, all the samples measured (Fig. 30b) showed only a difference under 3 per cent (Table 71).

Fig.30b. Frequency distribution for colony counts of Bacteria

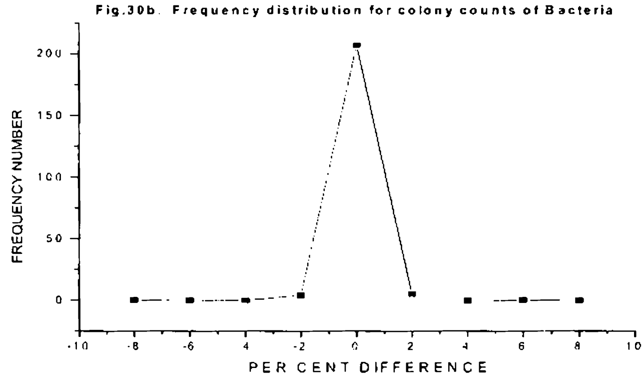


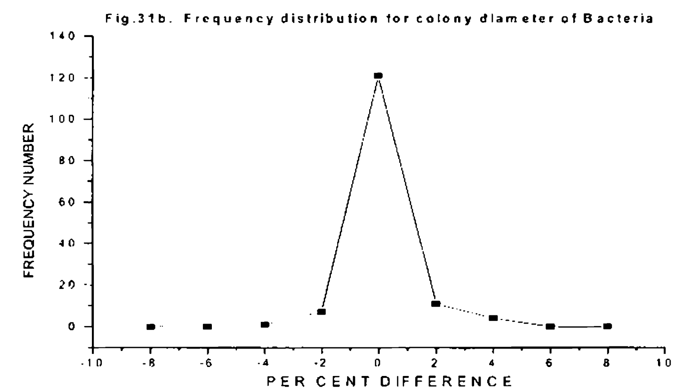
Table 71. Measurements in Bacteriology: Colony Counts.

Class Intervals	Frequency(percent)	Cumulative
0 difference	96	96
< 3% difference	4	100
<5% difference	0	100
<7% difference	0	100
<9% difference	0	100
Total	100	100

Diameter of bacterial colonies measured under the microscope using micrometers, in comparison with image analysis based measurements showed that 84 per cent of the measurements had no difference and 97 per cent of the data showed a difference under 3 per cent (Table 72). All the samples tested came under a difference of 5 per cent (Fig.31b).

Table 72. Measurements in Bacteriology : Colony diameter.

Class Intervals	Frequency(percent)	Cumulative
0 difference	84	84
< 3% difference	12.5	96.5
<5% difference	3.5	100
<7% difference	0	100
<9% difference	0	100
Total	100	100



Comparison between halo diameter measured using a scale / ruler and the same measured by image analysis showed that 66 per cent of the observations had no difference, 88 per cent had only under 3 per cent difference and 96 per cent of the readings (Fig.32b) displayed an under 5 per cent difference (Table 73).

Fig.32b. Frequency distribution for Halo diameter of Bacterial growth

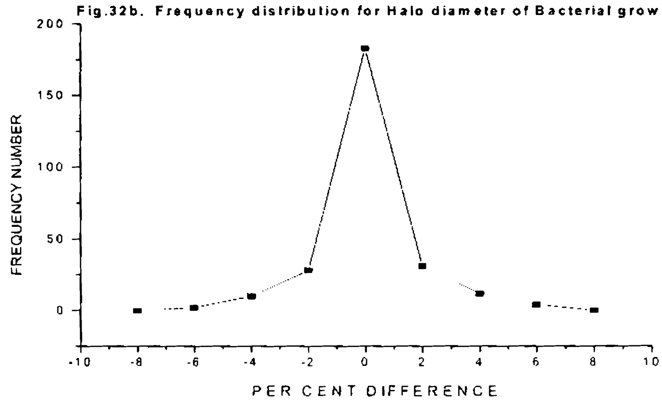


Table 73. Measurements in Bacteriology: Halo Diameter.

Class Intervals	Frequency(percent)	Cumulative
0 difference	68	68
< 3% difference	22	90
<5% difference	8	98
<7% difference	2	100
<9% difference	0	100
Total	100	100

Friedland *et al.* (2005) while carrying out studies on egg counting and sizing from scanned images for fecundity estimation studies successfully applied the technique of high resolution optical scans of plated oocytes using an image analysis software. Conducting estimates of false negatives in the results they stated that false negatives were as low as 1 per cent in the automated counts. Stevens (2006) worked on embryonic development and morphometry of eggs and developmental stages of the Blue King Crab, *Paralithodes platypus*. Digitally imaging the specimen at various intervals throughout the development using a compound microscope, he carried out the measurements by using an image analysis software. Of the seven morphometric parameters measured namely total area, yolk area, embryo length, embryo width, average diameter, eye length and eye width, the first two were measured on eggs and the remaining on embryos. Applying morphometric analysis techniques four indices were calculated.

Arnarson (1991) in his work on cod fish in September 1988 at the Bengenkop fishing factory in Denmark measured the fish both manually and by computer vision and expressed the difference between the two measurements graphically in centimeters. Histograms expressed the frequency numbers against the difference between the two readings showing a very clear normal distribution. Describing the possibility of errors, he went on to state that manual measurements had a standard deviation of 0.5 cm and a mean of 0.4 cm while the image analysis method showed a standard deviation of 0.45 cm. He further stated that the position of the length estimation line, the camera resolution, the capacity of the frame buffer, the blurr and optics were all factors influencing the accuracy. Arnarson in this work had resorted to expression of the difference between the two methods in real scale units of centimeters with a positive and negative difference perhaps on either side of a central histogram representing zero difference which fell within 0.25 cm, because only one morphometric length measurement of total length had been carried out by him. However, in studies like the current one, where nine morphometric measurements have been carried out on 2 species viz: Mackerel and Sardine and three each of morphometric measurements on two species of prawns and further measurements on cutlet length, width and area, width of two different coating materials like bread crumbs and rava and also colony diameter and halo diameter in bacteriological studies, it was felt that it would be more meaningful to give the difference in measurements between the two methods in percentage. A difference expressed in percentage is always comparable within data and between results so that it is possible to draw concrete conclusions on the trend.

In the case of fish there exists a linear relationship between the length of the fish and its weight. This forms the very basis for the length-weight relationship. It is known that the length-weight relationship is one of the standard methods yielding authentic biological information. It provides the means for calculating weight from the length of fish. Further, it is the direct way of converting logarithmic growth rates into weight and indicates the taxonomic differences in the life history such as metamorphosis and the onset of maturity (Venkataramanujam and Ramanathan, 1994). The genesis of this part of the present work lay here. The study was planned to establish a relationship between the weight of cooked prawn and the diameter of the heat-curled prawn.

Seventy eight specimen of peeled, deveined and cooked prawn subjected to diameter measurement by image analysis after accurately weighing them showed that 3 distinct groups of scatter existed in the correlation scatter diagram of the data (Fig.33).

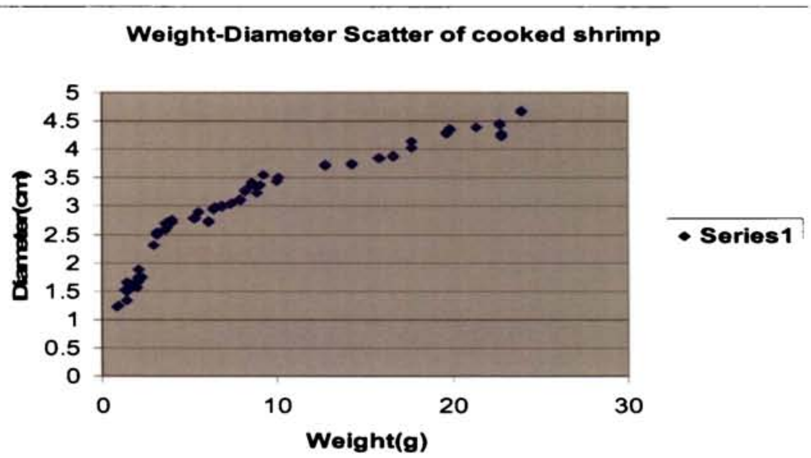


Fig. 33 Scatter Diagram for entire data (average values) of all prawns

Hence the entire lot of shrimps were subdivided into 3 sub-lots namely large, medium and small representing a weight range of 15g to 23g as large; 4g to 10g as medium and 0.1g to 4g as small (Figs.34, 35, and 36). The 3 sub lots were subjected to weighing, diameter measurement and Regression analysis.

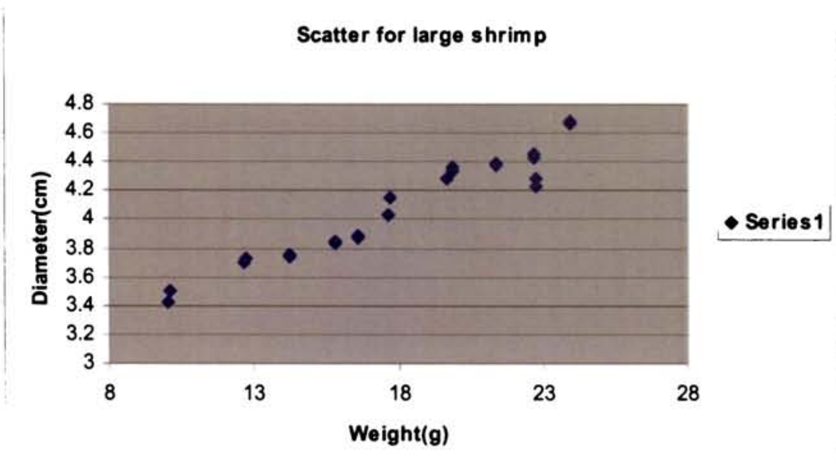


Fig.34. Scatter Diagram for large shrimp.

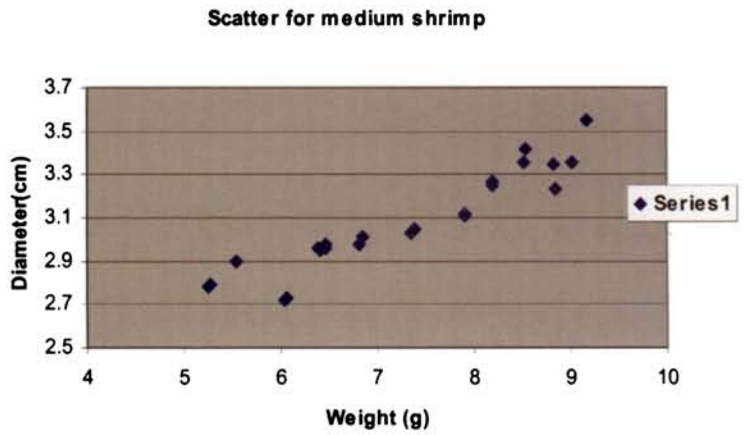


Fig.35. Scatter Diagram for medium shrimp.

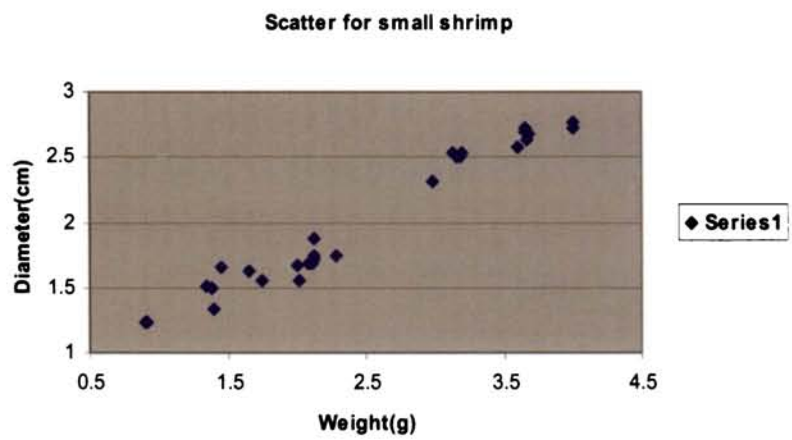
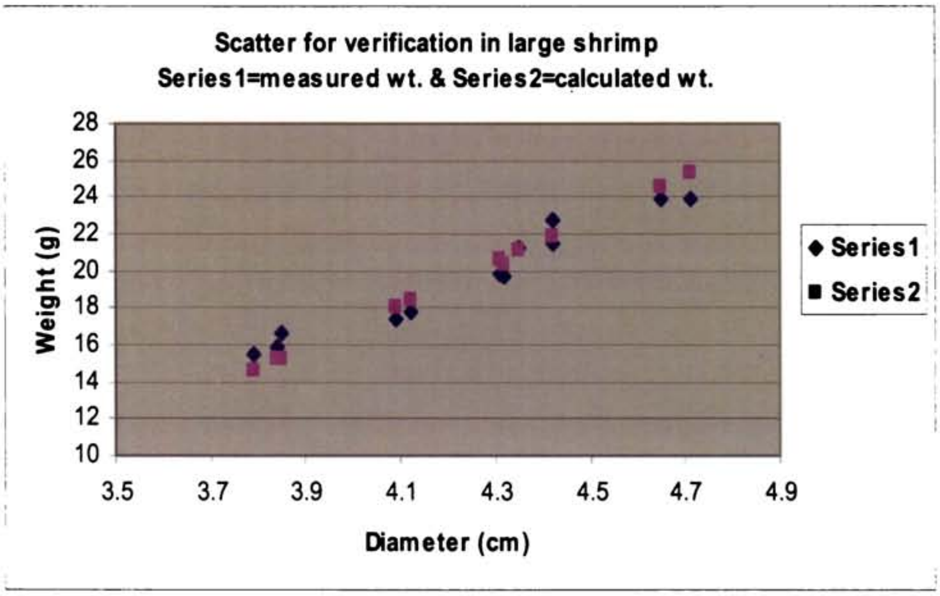


Fig. 36. Scatter Diagram for small shrimp

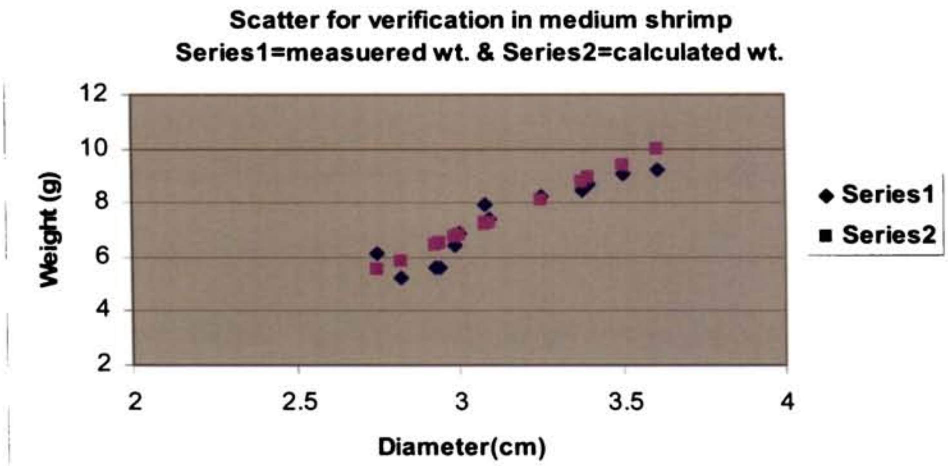
Model building involves three fundamental blocks. The three- step model building procedure includes planning, development and verification cum maintenance. The first but crucial step namely 'Planning' involves problem definition. The second block involves 'Development' which is concerned with writing the appropriate equations using the data collected and applying computer-aided statistical and mathematical tools (Saguy *et al.,* 1990). The Regression anova was worked out and the Regression output comprising the regression coefficient, the standard error, the probability value and coefficient of determination were worked out. The derived Regression model was given by the equation **W = 11.6352 D-29.53** for large shrimp. Similarly models for both medium and small prawns were worked out as **W = 5.19 D-8.76** for medium and **W = 1.76 D-1.07** for small shrimp.

Model building involves certain general principles of modelling and their application to food processing. Mathematically the formal way of describing any process is by deriving one or more equations expressed by the following functional relationship (using a vector notation) **y = f (x, p, e)** where y is the dependent variable vector, x is the independent variable vector, p is the vector parameter and e represents the error vector, which includes both the inherent and measured error. The model may be a linear and / or non- linear set of equations either algebraic, differential or partial differential that describes dynamic behavioural aspects of the system being analysed. This set is referred to as the mathematical model and is generally solved by applying a numerical scheme (algorithm) in a computer programme (Saguy and Karel, 1980; and Saguy et al., 1990).

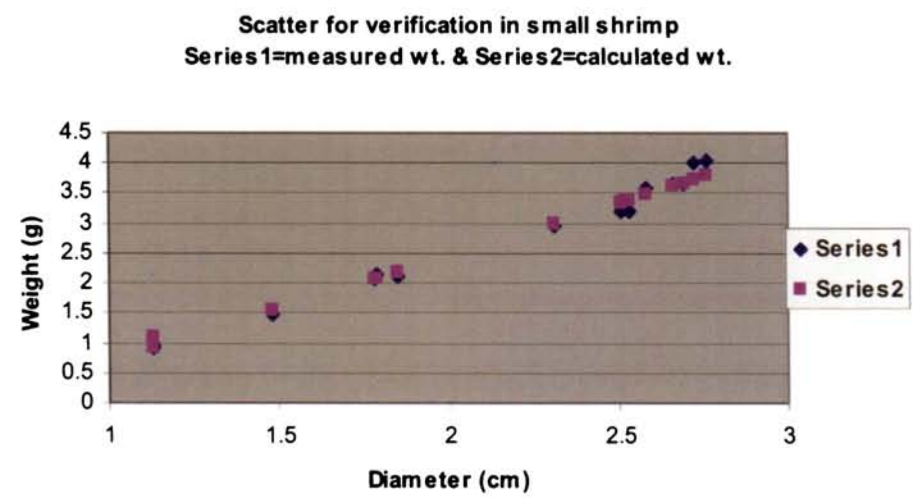
Models become dependable only if they are verified with an entirely new set of data. This verification was carried out in the case of all the measurements connected with the sub lots of large, medium and small prawns and subjected to correlation through scatter diagrams as can be seen from the figures (Figs.37, 38, and 39).



Verification scatter diagram - measured weight Vs calculated weight.
Fig.37. Large shrimp



Verification scatter diagram - measured weight Vs calculated weight.
Fig.38. Medium shrimp



Verification scatter diagram - measured weight Vs calculated weight.
Fig.39. Small shrimp

Studies on the correlation between the model-based calculated weights and the electronic balance-based measured weights showed very high correlation between the two sets of values. The correlation coefficient for small shrimp was 0.90, for the medium shrimp it was 0.87 and for the large shrimp it was 0.89. The figures clearly show the success of the model building process since the values show good correlation. Model building involves three fundamental blocks. The third block of model building involves 'Verification' and 'Maintenance' which facilitates verification of the model by comparing the results to a second set of data, not at all part of the model building data values (Saguy *et al.*,1990).

Linear programming can be used for simulation and optimization in industrial process. Bandoni doing modelling in an apple juice concentrate plant applied a Linear programming model. The objective function was the profit 'z'. The models developed provided data on the value of all the flow rates. Once these data were obtained and compared with the corresponding equipment capacities, a bottleneck analysis was carried out. Thus the influence of changes in costs, prices and capacities was studied using a modified LP technique. The utilization of linear programming for quality optimization was carried out by

Saguy(1988) in aseptic processing. The process utilizes HTST / UHT processing methods. Due to public safety considerations, the sterilization effects on microbial inactivation of low-acid foods is evaluated only during holding. For optimal process derivation, enzyme inactivation, microbial inactivation, cooking quality and retention of heat labile constituents are considered. The attributes chosen in this case were chlorophyll and thiamine retention in green peas. The initial simplex tableaux containing the linear programming coefficients for the optimization of HTST processing was prepared and the optimal solution derived by linear programming. Process modelling of potato blanching was done by Kozempel in developing a potato flake process simulator. A model could be developed only with good hard data of inputs and outputs and a knowledge of the equipment behaviour. The concern was to minimize the biological load in the outflow water and so a simulation centering around current operating conditions was simulated. Microscopic modelling in combination with optimization in the search for optimal drying profiles with a goal to maximize the rate of drying while minimizing or controlling undesirable side reactions which may have a negative effect on finished product quality (Saguy *et al.*, 1990). At the Institute of Thermophysics of the Odessa State Academy of Refrigeration at

Ukraine, mathematical models of the freezing process based on one-dimensional non-linear interpolating boundary problem of heat conductivity determined by kinetics of ice formation, were developed by Ghraizi *et al.* (1996). Simple algorithms of mathematical model numeric realization were built on the finite-difference method with local averaging of thermophysical properties in the neighbourhood of the integration points. The algorithm gives the opportunity to calculate the temperature profile, heat flow, mean enthalpy temperature, thickness of several frozen layers in any point of time and also the finite time of freezing for objects with arbitrary shapes. The importance of modelling in seafood quality and safety has been highlighted by Shahidi *et al.* (1997) in their book entitled seafood safety, processing and biotechnology. Total viable counts, differential counts and counts of specific spoilage organisms have been related to the remaining shelf life of various fresh fish products through predictive modelling by Dalgaard (1998) in his introduction on microbial methods and predictive modelling in food quality and standards for fisheries during the final meeting on concerted action on evaluation of fish freshness. A high degree of correlation was found between manual measurements and binary image measurements using image analysis as reported by Zion *et al.* (1999) in a study on fish sorting by computer vision. The reported results were obtained when they measured three fishes such as the Carp, the St. Peter's fish and the Grey Mullet based on moment invariants as well as geometric considerations such as shape of the whole body, shape of the tail or the fish length itself. Anon (2000 a) in a paper on modelling of seafood spoilage has described several empirical models for either freshness levels or for predicting the remaining shelf-life. These models were developed directly from storage trials, including the effect of temperatures, initial product quality or both. The microbial spoilage models were validated using the bias factor. The growth predictions were accurate but shelf-life predictions needed that each particular food was to be specified as well as that the conditions around the food were to be clearly and authentically defined. Themes such as predictive microbiology, modelling of microbial growth as a function of temperature, modelling for growth and survival using other factors, predicting changes in safety and quantity of chilled food products, prediction of microbial behaviour, time temperature integrators in food quality and shelf life, validity of models and also the reliability of any of these predictions have been discussed in detail at the International Institute of Refrigeration Conference at Quimper, France (Anon,2000 b). Sarkar *et al.* (2006) having predicted water temperature in a fish rearing tank by numerically solving governing equations of heat losses through conduction, convection, radiation and evaporation followed it up by validating the model using the predicted and experimental values of water temperatures. A correlation co-efficient of $r = 0.9$ and root mean square per cent deviation of $e = 1.67$ per cent proved the validity of the model.

Measuring morphometric parameters on eggs and larval developmental stages of the Blue king crab through image analysis, Stevens (2006 a; 2006 b) calculated four indices namely per cent yolk, elongation, ellipticity and circularity applying certain morphometric techniques. No standards existed, nevertheless, the indices were developed by Stevens. McGarvey *et al.* (2007) partitioned fish numbers within each cohort into length bins called slices thus facilitating partition of the continuous length-at-age distribution, thereby differentiating legal fish from sub-legal ones. Thus it was shown that fish numbers vary dynamically with length as well as age in the model population array. This made it possible to model fish numbers for stock assessment based on length dependent change. A method for measuring the body length of landed fish using an image analysis technique highlighted that fork length measurements on Yellow sea bream, *D. tumifrous* photographed inside fish boxes and containers at a fishing harbour, had distortions due to bending of fishes inside the containers. Two correcting functions FLic1 and FLic2 were applied here. Mean fork length FLn for each size class, N number of individuals inside a container, was closely simulated by an allometry function, FLn = 67.1 NE - 3.38 (Imai and Yamamoto, 2007). Modelling of the degree of fish contamination with 90Sr in relation to the Calcium concentration in water as reported by Kryshev (2008) showed that an empiric relationship existed. A set of data on the equilibrium concentration factors of 90Sr in fish, in relation to the Calcium concentration in water was analysed. Katsanevakis and Maravelias (2008) trying to establish that a Multi Model Inference is better than the Von Bertalanffy Growth Model Equation to study fish growth, used 133 sets of length-at-age data with 4 candidate models fitted to each data set with the application of VBGM, the Gompertz Model, Logistic and Power Models.

The application of engineering and technological sciences to describe mathematically or statistically a process and its performance is modelling. It can take place before the actual system is built or it can be applied to improve an existing system. The more complex the system and the greater the number of interactions between its constituents, the more valuable it is to use modelling. The reasons for adopting these techniques are multiple and include: improving quality, improving yields, predicting operability, developing control strategies, cutting costs, evaluating alternatives, changing operational modes, analysing risks, de-bottle-necking, formulating start-up, shut-down and change over policies and parametric sensitivity studies. The model can be static, focused on steady state operation, or dynamic, focused on transient state. It can be fully deterministic, not allowing for variation, or probabilistic with time-varying parameters. What makes modelling particularly valuable nowadays is the widespread use of computers. The computer brings in the power to handle large quantities of information and solve hundreds and thousands of equations in a very short time and this is a great advantage to the scientific and engineering community.Therefore once the models are set and validated, one can "test drive" all kinds of hypotheses and play "what if" scenarios in the time it takes to introduce the fractional data changes required. Modelling is an important approach to a number of problems in the food industry and can solve such problems with the involvement of multidisciplinary inputs such as engineering, mathematics, statistics, numerical analysis and computer software expertise. However, an intimate familiarity with both the system and the problem being analysed is also absolutely essential for achieving high success rates in bioprocess engineering situations within the production realm of the processed food industry. In the seafood processing industry, the emergence of a myriad number of productin lacunae do exist. It is the responsibility of the scientists and engineers conducting research in the field to come up with management solutions for the same.

6. SUMMARY

Chapter. 6 *Summary*

The application of computer vision based quality control has been slowly but steadily gaining importance mainly due to its speed in achieving results and also greatly due to its non- destructive nature of testing. Besides, in food applications it also does not contribute to contamination. However, computer vision applications in quality control needs the application of an appropriate software for image analysis. Eventhough computer vision based quality control has several advantages, its application has limitations as to the type of work to be done, particularly so in the food industries. Selective applications, however, can be highly advantageous and very accurate.

The present study was initiated with the following objectives:

i) To identify and select certain potential areas where computer vision based quality control could be applicable.

ii) To compare the conventional / existing methods of quality evaluation with new image analysis route of quality evaluation.

iii) To establish accuracy and dependability of computer vision based image analysis techniques to carryout quality evaluations.

The salient findings of the study were:

- Computer vision based image analysis could be used in morphometric measurements of fish with the same accuracy as the existing conventional method.
- The method is non-destructive and non-contaminating thus providing an advantage in seafood processing.
- The images could be stored in archives and retrieved at anytime to carry out morphometric studies for biologists.
- Here the image analysis based measurements showed high accuracy to the extent that among the nine standard morphometric lengths measured namely total length, fork length, standard length, body depth, snout length, eye diameter, post orbital length, head length and caudal peduncle height, 30 to 53 per cent of the measurements showed no difference, 31 to 52 per cent showed a difference of less than 3 per cent, and 9 to 23 per cent showed a difference of under 5 per cent. Thus a total of 90.5 to 96 per cent of all the measurements showed only a difference of less than 5 per cent between the two techniques in the case of Mackerels.

- In the case of Sardines also the same nine standard morphometric lengths were measured to test for accuracy of the image analysis route of measurement. The findings were that while 34 to 54 per cent of the measurements showed no difference for all the nine morphometric lengths, 25 to 51 per cent of the measurements showed under 3 per cent difference and 10 to 20 per cent showed a difference below 5 per cent. Thus a total of 88 to 96 per cent of the measurements showed only a difference of less than 5 per cent between the two techniques.
- Computer vision based image analysis could be used in the morphometric measurements of prawns also. Here too the method is non-destructive and non-contaminating, and an advantage in processing. Besides, the images could be retrieved from the archives any time and the morphometrics carried out.
- Here image analysis measurements showed a high degree of accuracy to the extent that of the three standard morphometric lengths measured namely total length, body length and carapace length in case of prawn *Fenneropenaeus indicus*, 39 to 43 per cent of the measurements showed no difference compared to the conventional technique,41 to 43 per cent showed a difference below 3 per cent, meanwhile 9 to 10 per cent of the measurements had only

an under 5 per cent difference. Thus a total of 91 to 92 per cent of the entire measures showed only an under 5 per cent difference between the two techniques.

- In the case of *Penaeus monodon* the same three standard morphometric measurements were done. The accuracy of the image analysis method of measurement was evident here too. Here 40 to 42 per cent of measurements had no difference, 40 to 44 per cent showed a difference of under 3 per cent and 8 to 10 per cent of measurements showed an under 5 per cent difference. Thus a total of 90 to 96 per cent of the measurements showed only a difference of under 5 per cent between the two techniques.
- Computer vision and subsequent image analysis could be used in measurements of various food products to assess uniformity of size. One product namely cutlet and product ingredients namely coating materials such as bread crumbs and rava were selected for the study.
- Computer vision based image analysis was used in the measurements of length, width and area of cutlets. Also the width of coating materials like bread crumbs was measured.

- Here the image analysis based measurements showed high accuracy to the extent that the length, width and area of cutlets measured conventionally using scale/ruler and calculator was compared with measurement of all the three parameters using the image analysis software. The results showed that 56 to 69 per cent of the measures showed no difference, 23 to 26 per cent of the measurements showed a difference under 3 per cent and 8 to 17 per cent of the measurements showed a difference under 5 per cent between the two techniques. Thus a total of 96 to 100 per cent of the measurements had only a less than 5 per cent difference between the two techniques
- Computer imaging and further image analysis could be very effectively used for quality surveillance in the preparation of uniformily shaped / sized food products like cutlets, fingers, burgers tablets etc.
- Image analysis could detect deviations in size, shape, contours, surface finish etc. so that corrective measures could be taken as and when required.
- Measurements of width of the particles of coating materials, bread crumb and rava conventionally under a microscope and comparison with the same measured by image analysis route showed that 51 to 56 per cent of the

measurements had no difference, 27 to 29 per cent measurements showed difference under 3 per cent and 15 to 16 per cent measurements showed a difference below 5 per cent. Thus a total of 96 to 98 per cent of all the measurements recorded a less than 5 per cent difference between the two techniques.

- Computer imaging and subsequent image analysis can be very effectively used in quality evaluations of product ingredients in food processing. Measurement of width of coating materials could establish uniformity of particles or the lack of it.
- The application of image analysis in bacteriological work was also done.
- Image analysis showed tremendous promise in colony counting. Both automatic colony counting and manual colony counting was possible with image analysis softwares. However, here, only manual counting using tags were applied for comparison with the conventional manual counting using the Quebec colony counter.
- The colony counting by image analysis showed very high accuracy. While 96 per cent of the readings showed zero difference, the rest of 4

per cent of the readings showed a difference of under 3 per cent. Thus all the counting trials showed an under 3 per cent difference.

- The measurement of colony diameter for qualitative studies also showed promise so also the measurement of clear zones (halos) in the tests for antibiotic/antimicrobial activity studies. While 68 to 84 per cent of the measurements showed no difference, 12.5 to 22 per cent of the measurements showed a difference under 3 per cent and 3.5 to 8 per cent of the measurements revealed a less than 5 per cent difference. Thus a total of 98 to 100 per cent of the measurements showed a less than 5 per cent difference between the two techniques.
- Qualitative studies in bacteriology involves measurement of colony size as a means of detection of species. Image analysis application in measurements in such situations show tremendous promise. Clear zones on culture plates indicate antibiotic /antimicrobial /chemical activity inhibiting growth of microbes (halos). The width or diameter of the halo varies linearly as the strength or activity of the medicine/chemical which is tested. Image analysis based measurement has shown its worth here.

- Size grades are number of pieces per pound or kilo. The larger size grades fetch higher price. A linear relationship was established between the weight of cooked prawn and the diameter of the heat curled prawn.
- Three mathematical models were developed for large, medium and small sized prawns so that the weight of a cooked shrimp could be computed from the diameter measured from the image of the heat curled prawn.
- The models were:

W = 11.6352D – 29.53 for large sized prawns,

named **KRIMSNON I**

W = 5.19D – 8.76 for medium sized prawns,

named **KRIMSNON II**

W = 1.76D – 1.07 for small sized prawns

named **KRIMSNON III.**

- The weight of an individual piece of prawn can be computed from the measurement of its width using an image of the heat curled prawn.

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APPENDIX – I

(In press – Journal of the Marine Biological Association of India)

IMAGE ANALYSIS IN THE MORPHOMETRIC MEASUREMENT OF TWO SPECIES *Rastrelliger kanagurta* (Cuv.), THE INDIAN MACKEREL AND *Sardinella longiceps*, Val., THE INDIAN OIL SARDINE

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ABSTRACT

Morphometrics are important in relation to length-weight relationship studies that yield authentic biological information. The accuracy of image analysis in measurement of nine standard morphometric lengths on mackerels and sardines were compared with the conventional method. Total length, fork length, standard length, body depth, eye diameter, snout length, post orbital length, head length and caudal peduncle height were measured by both the existing conventional technique and through an image analysis route. Algorithms were also described for the same. Samples comprised of 288 mackerels and 253 sardines procured in small lots over a period ranging over one year. The image analysis measurements showed very good accuracy when compared with corresponding values obtained by manual measurements. In the case of mackerels 30 to 53 per cent of the measurements representing all the nine morphometric lengths showed no difference, 70 to 84 per cent showed less than 3 per cent difference and 91 to 96 per cent showed less than 5 per cent difference. With regard to sardines 34 to 54 per cent of the measurements representing all the nine morphometric lengths showed no difference, 69 to 85 per cent showed less than 3 per cent difference and 88 to 96 per cent of the measurements showed less than 5 per cent difference . The results proved that digital image processing and morphometric measurements using image analysis was accurate and dependable.

Key words: morphometrics, mackerel, sardine

INTRODUCTION

Among some of the standard methods applied for gathering reliable biological information, morphometric measurements play a significant role. It facilitates calculation of weight of fish from length. Conversion of logarithmic growth rates into weight, indication of taxonomic differences and events in the life history of fishes such as metamorphosis and onset of maturity are also possible through mophometric studies. Measurable characters such as total length, standard length, fork length, body depth, head length, pre-opercular length, eye diameter, pre-dorsal length, post-opercular length of fins, including the first dorsal, the second dorsal, the pre- anal, and the upper and lower lobes of the caudal fin are generally measured. The measurements are generally made sex-wise, over wide size ranges of fish, using a fine draftsman dividers and a measuring board and this is recorded to the nearest 0.5 mm or 1 mm (Venkataramanujam and Ramanathan, 1994). In the case of crustaceans such as shrimp, the measurements made are limited to the total length, body length and carapace length (Rao *et al.*, 1995). Measurement of fish at the site of catch or landing centre or market place often posses serious hassles. Conventionally biologists often resort to purchasing the fish and transporting them to the laboratories. If the destination is quite far, the fish is preserved in formalin. Digital imaging has facilitated a non destructive method of immediately capturing the image of the fish or prawn being studied and storing the images in the digital camera. The images can be later transferred to a computer and by applying an appropriate application software can be subjected to morphometric measurements using image analysis.

The accuracy of the digital image analysis method had to be tested vis-à-vis the conventional technique. This was attempted using more than 250 samples each of sardines and mackerels to represent fishes.

REVIEW OF LITERATURE

When the objective of a study using computer vision is image analysis, the algorithm plays a vital role in achieving the type of analysis and in arriving at meaningful interpretations. The technique of sorting fish by species was reported by Tayama *et al.* (1982) and Wagner and Walter (1983).While the former developed a machine to identify fish by species using shape descriptors, the latter used measurement of the backline of a fish from nose to the tail stalk as a criterion for distinction. Wagner *et al.* (1987) also described a method of species identification using shape descriptors achieving a reliability of 90 per cent. Strachan *et al.*(1990) compared three techniques of shape analysis such as invariant moments, superimposition and shape descriptors to achieve 73.3 per cent, 63.3 per cent and 90 per cent reliability in identification of fish species.

Arnarson *et al.* (1991) working on vision applications in the fish industry threw light on the applications in sorting situations. Nielsen *et al.* (1991) giving an overview of vision opportunities in quality assurance, emphasized the accuracy of computer vision. Vision techniques were also excellent for their effective role in trimming and portioning. Strachan and Murray (1991) reported that image analysis systems existed for species and size grading as well as morphological studies. Zion *et al.* (1999) reported that moment invariants and geometric considerations were relied on for fish sorting. Taira *et al.* (2005) have described a discriminant method using neural networks for fish species identification. Dunbrack (2006) had conducted in situ measurements of fish body length using perspective based remote stereo video. Kiessling *et al.*(2006) used image analysis to measure whole fillet contraction studying the effect of pre and post mortem temperature on rigor. Morphometric measurements on preserved lampreys using image analysis techniques were successfully carried out by Neave *et al.* (2006). Morphometric parameters on the embryonic development of the blue king crab *Paralithodes platypus* was studied using image analysis by Stevens (2006). White *et al.* (2006) used moment invariant technique to differentiate morphological make up of fish by computer vision. Imai and Yamamoto (2007) reported application of image analysis in measuring fork length of fishes inside polystyrene containers at the landing centres. Misimi *et al.* (2008) reported a measurement technique to evaluate changes to the shape and size of pre and post rigor salmon and cod fillets using a computer vision .

MATERIALS AND METHODS

Any image analysis studies would involve stages such as image capture, image transfer-storage and image analysis-interpretation. A 5 mega pixel digital camera was used for image acquisition. For uniformity of illumination, an image recording box made of fibre board 36.5cm x 27.5cm x 20.5cm dimensions covered with white matt finish paper on the inside was set up. Lighting with 10 lux brightness was provided and the camera positioned at the top. The images were transferred to computers. A custom made image analysis software was loaded into the computers for carrying out measurements.

Morphometric measurements were carried out on fish.The species selected were *Rastrelliger kanagurta*, the Indian mackerel and *Sardinella longiceps*, the Indian oil sardine. Fishes of varying sizes were collected from the markets regularly over a period of more than one year. In all 288 mackerels and 253 sardines were selected for the study. The method described by Venkataramanujam and Ramanathan (1994) was followed for manual morphometric measurements using fine draftsman dividers and a graduated ruler. Nine morphometric lengths namely total length, fork length, standard length, body length, eye diameter, snout length, post orbital length, head length and caudal peduncle height were measured manually, fishes digitally imaged inside the box, and images transferred to the computer. Using the image analysis software, each one of the nine morphometric measurements were done on the images on screen (Figs.A,B). The algorithm followed was: ***select image – filter – select measure – select length – calibrate – measure – open spread sheet – print.***

The data obtained thus was subjected to data processing. The difference between each manual measurement and its corresponding image analysis measurement in the case of every morphometric length relating to every specimen was computed and classified as class intervals from zero difference to 9 per cent difference on both the positive and negative side. The conventional method was taken as standard and hence the variation shown by the image analysis measurement was classed as zero/positive/negative. One per cent difference on both the positive and negative sides was considered as zero difference and represented by a single class interval. The other class intervals were +1 to +3 per cent ; +3 to +5 per cent ; +5 to +7 per cent and +7 to +9 per cent respectively. Similarly 4 class intervals existed on the negative side too thus making up a total of 9 class intervals for each morphometric length. The frequency distribution was determined and represented in the form of histograms.

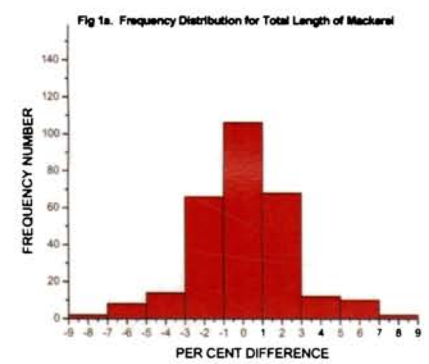
Fig. A. Morphometric measurements for mackerel by image analysis

Fig. B. Morphometric measurements for sardine by image analysis

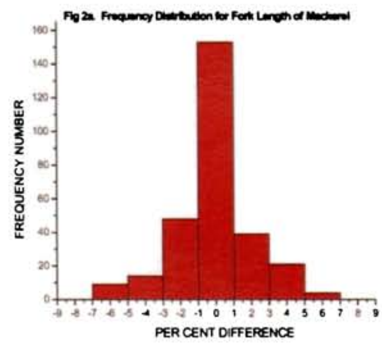
RESULTS AND DISCUSSION

The difference shown by the image analysis measurement with the corresponding conventional manual measurement was recorded as zero difference / positive difference / negative difference. The frequency distribution was worked out for each morphometric length. In total 9 morphometric lengths were measured for mackerels as well as sardines.

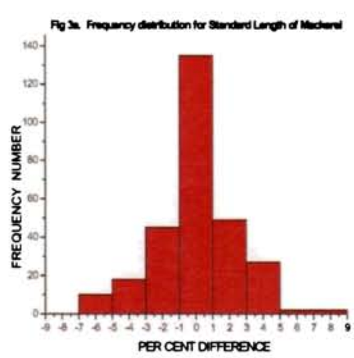
The morphometric measurements on mackerel was carried out for nine different length measurements. In total 288 fishes were subjected to measurement both manually and correspondingly by image analysis too. The difference between the two was computed, converted into percentage and expressed as frequency distribution into nine class intervals, four on the positive side and four on the negative, on either side of a zero class interval. The frequency distribution relating to each morphometric length was then worked out and represented by histograms. In the case of total length, 51 per cent of the readings (147 nos. out of the 288 total nos.) showed no difference and 31per cent of the measurements showed a difference of less than 3 per cent. While 14 per cent of the measuremnts showed a difference less than 5 per cent, only 4 per cent showed a difference of less than 7 per cent in values (Fig.1a).



In the case of fork length measurements 53 per cent of the measurements showed no difference (153 nos. out of 288 total nos.) and 30 per cent of them showed less than 3 per cent difference. While 12 per cent of the measurements were seen to show a difference of 5 per cent, about 4.5 per cent of them only displayed a difference of 7 per cent between the two (Fig.2a).

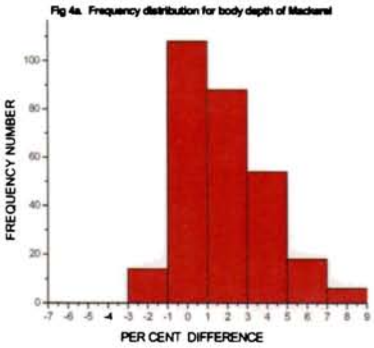


As for standard length, the no difference class interval was represented by 47 per cent of the measurements and 33 per cent of the measurements accounted for a difference of less than 3 per cent. Meanwhile 16 per cent of the measurements accounted for less than 5 per cent difference and 4 per cent of them represented less than 7 per cent difference in the readings between the two methods. Also a meagre 0.7 per cent of the measurements stood in the under 9 per cent range (Fig.3a).



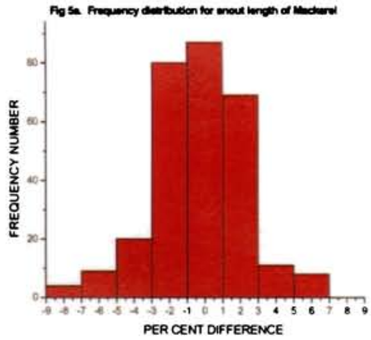
For body depth measurements, while 38 per cent of the measurements showed no difference, about 35 per cent of them showed an under 3 per cent difference and 19 per cent of them showed a below 5 per cent difference between the two methods. The difference in the case of 6 per cent of the measurements was below 7 per cent and a meagre 2 per cent only represented the range of difference within 9 per cent. The readings were specifically skewed towards the positive side. Only 5 per cent of the image analysis readings were lower than the manual readings, and 95 per cent of them showed values higher than the manual measurements. This was an aberration seen in the case of body depth measurements (Fig.4a).

Fig 4a. Frequency distribution for body depth of Mackerel



Snout length measurements showed 30 per cent of the measurements with no difference, 52 per cent of them with a less than 3 per cent difference, 11 per cent of the measurements with an under 5 per cent difference and 6 per cent of them with a below 7 per cent difference. The readings showing an under 9 per cent difference was a meagre 1 per cent (Fig.5a).

Fig 5a. Frequency distribution for snout length of Mackerel



Eye diameter measurements showed the following trend. While 34 per cent of the measurements showed no difference, 38 per cent of them showed a less than 3 per cent difference. In the case of the below 5 per cent difference class interval, the frequency was 18.5 per cent, while 10 per cent of the measurements showed a less than 7 per cent difference (Fig.6a).

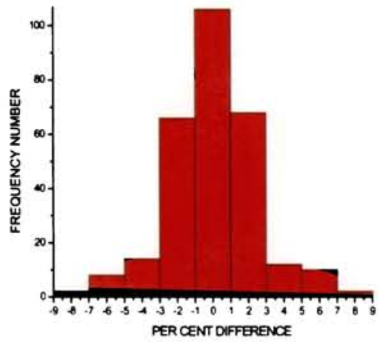


Fig 6a. Frequency distribution for eye diameter of Mackerel

Post orbital length measurement when analysed showed that 37 per cent had no difference, while 47 per cent showed less than 3 per cent difference. Less than 5 per cent difference was represented by 9 per cent of the measurements while 6 per cent readings fell in the under 7 per cent difference range and a paltry 1.4 per cent represented the under 9 per cent difference (Fig.7a)

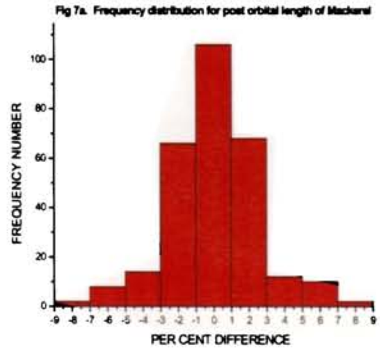


Fig 7a. Frequency distribution for post orbital length of Mackerel

In the case of head length, while 35 per cent represented no difference, 48 per cent showed a difference of only under 3 per cent, 11.5 per cent showed a difference of under 5 per cent and 5.5 per cent showed an under 7 per cent difference (Fig. 8a).

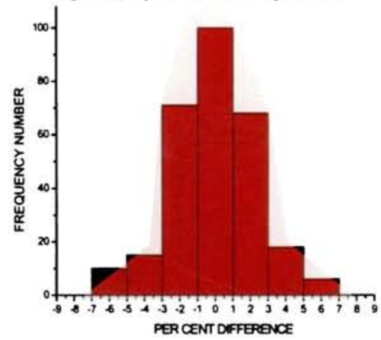


Fig 8a. Frequency distribution for head length of Mackerel

The caudal peduncle measurements showed that there was no difference for 31 per cent of the readings and under 3 per cent difference for 39 per cent. A below 5 per cent difference was shown by 23 per cent, while 5 per cent of the readings displayed less than 7 per cent difference. Under 9 per cent difference was shown by a meagre 3 per cent (Fig.9a).

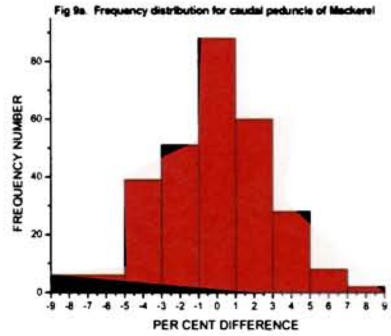
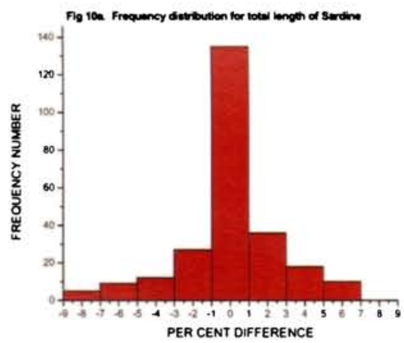


Fig 9a. Frequency distribution for caudal peduncle of Mackerel

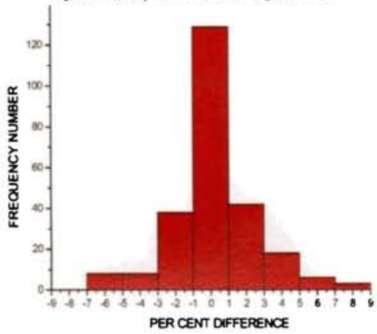
Sardines were also subjected to morphometric measurements of 9 different measurements namely total length, fork length, standard length, body depth, snout, eye diameter, post orbital, head length and caudal peduncle. In all 252 number of sardines were subjected to this study. The measurements were carried out manually and by image analysis and the difference computed and percentage difference determined. The differences thus obtained were categorised into 9 class intervals of percentage difference, the zero difference falling within one percent on both the higher side and lower side of zero and the remaining 8 class intervals four on the positive for higher image analysis readings and four on the negative accounting for lower image analysis readings from the conventional manual measurements which was taken here as standard to compute the variations of the image analysis readings for the comparative study.

Total length measurement revealed that 54 per cent of the fishes measured showed no difference while 25 per cent showed a difference of 3 per cent. A below 5 per cent difference in the readings was recorded in the case of 12 per cent of measurements, a less than 7 per cent difference was noted in the case of 7.5 per cent of measurements and an under 9 per cent difference was recorded by 2 per cent of the measurements while comparing manual measurements against image analysis morphometric measurements(Fig.10a).



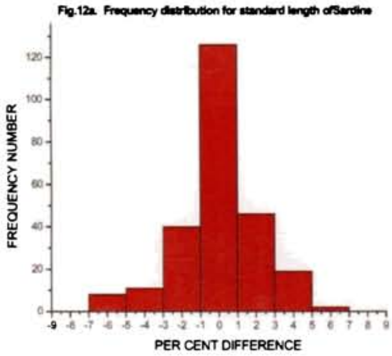
While measuring fork length it was noticed that 51 per cent of the measurements showed no difference, 32 per cent showed a difference of under 3 per cent and 11 per cent showed an under 5 per cent difference. While 6 per cent of the measurements showed an under 7 per cent difference, only a meagre 1 per cent showed a difference between 7 and 9 per cent. This is clearly shown in the respective histogram (Fig.11a).

Fig 11a. Frequency distribution for fork length ofSardine



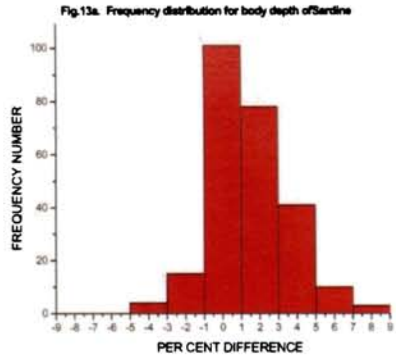
Morphometrics of standard length showed that 50 per cent of measurements had no difference, while 34 per cent showed a difference of under 3 per cent, 12 per cent of measurements had a difference of under 5 per cent while 4 per cent of them only showed a difference of under 7 per cent (Fig.12a).

Fig.12a. Frequency distribution for standard length ofSardine



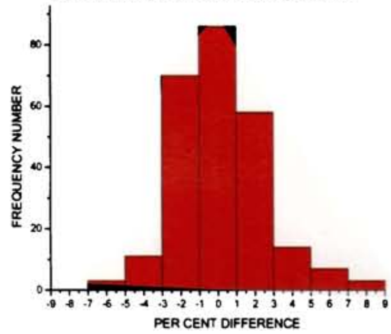
Body depth measurements showed that while 40 per cent of the measurements had no difference, 37 per cent had a difference of under 3 per cent. A below 5 per cent difference was shown by 18 per cent of the measurements, while only 4 per cent of measurements had a difference between 5 and 7 per cent. A difference of 7 to 9 per cent was shown by a paltry 1 per cent only (Fig.13a).

Fig.13a. Frequency distribution for body depth ofSardine



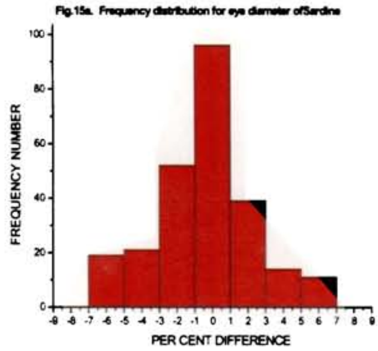
The entire readings of body depth was found skewed towards the positive side showing that only 7.5 per cent of the image analysis measurements were less than the manual measurements. The entire remaining 92.5 per cent of the measurements showed a higher value than manual measurements. Measurement of the snout showed that 34 per cent of the measurements had no difference, while 51 per cent showed a difference of under 3 per cent only. A difference of under 5 per cent was shown by 10 per cent of the measurements and a difference of under 7 per cent and a difference under 9 per cent by 4 per cent and 1 per cent of the measurements respectively (Fig.14a).

Fig.14a. Frequency distribution for snout length ofSardine



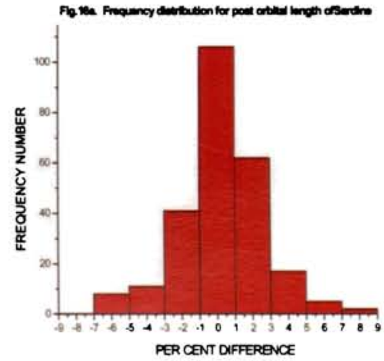
Morphometrics of eye diameter showed that 38 per cent of the measurements had no difference. However, 36 per cent, 14 per cent and 12 per cent of the measurements showed differences of under 3 per cent,under 5 per cent and under 7 per cent(Fig.15a).

Fig.15a. Frequency distribution for eye diameter ofSardine



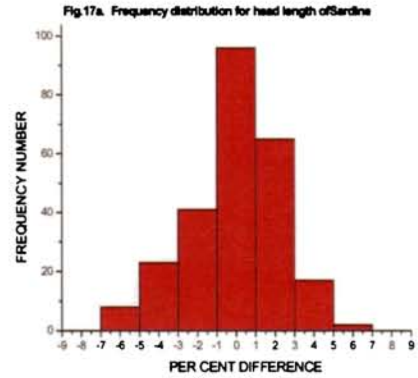
Measurements of post orbital length revealed that 42 per cent of the measurements had no difference, closely followed by a difference of under 3 per cent shown by 41 per cent. However, 11 per cent of measurements showed a difference of under 5 per cent while 5 per cent showed a difference under 7 per cent and a meagre 0.8 per cent showed a difference under 9 per cent (Fig.16a).

Fig.16a. Frequency distribution for post orbital length ofSardine



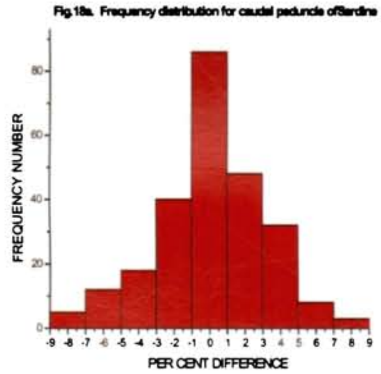
For head length measurements 38 per cent readings showed no difference. However, 42 per cent showed a difference under 3 per cent and 16 per cent and 4 per cent showed a difference of under 7 per cent and 9 per cent respectively. (Fig.17a).

Fig.17a. Frequency distribution for head length ofSardine



For the last item namely caudal peduncle, the results were as follows. 34 per cent of the measurements had no difference, while 35 per cent showed only a difference of under 3 per cent. Meanwhile, 20 per cent, 8 per cent and 3 per cent of the measurements showed a difference of less than 5 per cent, less than 7 per cent and under 9 per cent respectively (Fig.18a).

Fig.18a. Frequency distribution for caudal peduncle ofSardine



Every measurement on nine different morphometric lengths in both mackerels and sardines using the existing conventional manual method using draftsman's dividers and a graduated ruler and comparing it to an image analysis technique showed remarkable closeness between the values obtained. Difference between manual measurements and image analysis based measurements were recorded as zero difference / positive difference / negative difference as the case may be and frequency distribution calculated. The comparisons between the two techniques of measurement and the relative differences between variations obtained for all the 9 standard lengths measured should provide meaningful interpretations only if the difference was expressed in percentage and not in real scale measures. A normal frequency distribution curve was observed in all cases. The total length, fork length and standard length showed that nearly 50 per cent of the measurements had no difference and another 30 per cent showed under 3 per cent difference. A difference of 3 to 5 per cent was shown by another 15 per cent of the data. Thus roughly 95 per cent of all the measurements fell within a 5 per cent margin of difference. The graphs representing these 3 sets of measurements showed very similar trends and were well within comparable limits in mackerels. A similar pattern was exhibited by the other six morphometric measurements namely body depth, snout length, eye diameter, post orbital length, head length and caudal peduncle height. In all cases it was noticed that a zero difference was shown by 30 to 40 per cent of the measurements while a total of 70 to 85 per cent of the measurements had an under 3 per cent difference. In all, an under 5 per cent difference was shown by nearly 90 to 95 per cent of the measurements . All these observations showed good agreement with the results reported by Arnarson (1991).

The results obtained in the case of morphometric measurements on sardines were no different. The first three length measurements namely total length, fork length and standard length showed that 50 to 55 per cent of the measurements had no difference, while 80 to 85 per cent of the readings showed a difference under 3 per cent and 91 to 96 per cent of the recordings had only a difference under 5 per cent. The other shorter lengths measured namely body depth, snout length, eye diameter, post orbital length, head length and caudal peduncle length showed similar and comparable results. The results were almost identical to those obtained in the case of mackerel. While 35 to 45 per cent of the measurements had no difference, nearly 70 to 85 per cent of the readings had only a difference under 3 per cent and nearly 88 to 96 per cent of the observations had only a difference of under 5 per cent . These results too are in good agreement with the results on the measurement of length in cod reported by Arnarson (1991).

In the case of short length measurements such as snout length, eye diameter and caudal peduncle length, the spread was found wider with a higher percentage representation in the 1 to 3 per cent difference range and the 3 to 5 per cent difference range in comparison with the differences shown by the other six measurements such as total length, fork length, standard length, body depth, head length and post orbital length. The body depth measurement differences showed a definite skew towards a positive difference for the image analysis measurements suggesting that probably dividers when used for manual measurements could have pressed on to the soft bellies resulting in a constant lower reading than the software based measurements.

The reliability in application of the new experimental computer vision cum software based technique in morphometrics seemed quite evident. The results obtained were very well in consonance with the results and inference reported by Arnarson (1991) in his studies on morphometric length measurements in cod fish for the purpose of sorting before feeding them to decapitating and /or filleting machines.

Strachan *et al.*(1990) while doing a comparative study of three methods of shape analysis of digital images to establish the best method to identify fish species, stated that measurements applying the image analysis route was inevitable in this sort of studies. The application of invariant moments, the superimposition of the sample image over a template and thirdly the use of shape descriptors were the three techniques tried to sort fish species wise. A sorting reliability of 73.3 per cent, 63.3 per cent and 90 per cent respectively was the outcome, the lower level of reliability seen in the case of the superimposition technique being justified by the computationally intensive work involved here. Arnarson *et al.* (1991) in their paper on vision applications in the fishing and fish product industries had emphasized the importance of measurements by the image analysis route in fish sorting by length and the estimation of weight from length. They went on to state that such measurements could serve as input attributes for processing machines that went on to decapitate, eviscerate or fillet the fish. According to them product sorting involved dispatching products according to shape, size and weight and here also the former two needed measurement of dimensions the image analysis way. Nielsen *et al.* (1991) in an overview of vision opportunities in quality assurance had stated that image analysis based measurements had a future because of its accuracy. Zion *et al.* (1999) who did sorting of fish by computer vision had stated that high correlation was found between manual measurements and binary image measurements using image analysis. De Wet *et al.* (2005) worked on computer assisted image analysis as an alternative method to determine body weight and condition of fish with allometric growth. A relationship between body weight, length, depth, image pixel surface count and image pixel periphery count of the same species in a fixed weight range was studied and a goodness of fit regression equations computed by them. Dunbrack (2006) carried out fish body length measurements using in-situ measurement techniques based on photographic / video image analysis. He reported that lengths of PVC pipes measured both under water and in air differed by an average difference of only 1.6 per cent. Replicate length measurements conducted by him on free-swimming bluntnose six gill sharks *Hexacanthus griseus* also differed by an average difference of only 1.6 per cent. Neave *et al.* (2006) while studying the effects of preservation by formalin or alcohol on length variations of preserved specimen for biological studies applied image analysis based length measurements on the specimen samples for six standard morphometric length measurements and ten areas of pigmentation. These were measured and analysed by multiple measurements over time and the results subjected to regression analysis. The regression equations could allow for accurate correction of preservation effects on morphometrics. White *et al.* (2006) doing automated measurement of length of fish by computer vision using an automatic equipment called "The Catchmeter" found that image processing and image analysis technique could measure the length of every specimen with a standard deviation of a mere 1.2 mm. Imai and Yamamoto (2007) applied a method for measuring the body length of landed fish using an image analysis technique. Fork length measurements by the application of image analysis was successfully carried out on yellow sea bream (*Dentex tumifrous*) landed at the Shimonoseki port fish wholesale market. In total 2938 individuals were measured from 367 images with two correcting functions applied for neutralizing the bent positions of the fish inside containers / fish boxes.

The application of image analysis in morphometry has a future since digital imaging can be done very easily under any sort of field conditions. The process is non-destructive and the advantage of storing the images in the archives for the morphometric measurements to be carried out at a future date, place and time is of interest to all biologists. The scope for morphometric measurements prior to the fish being fed into processing machinery such as the deheader, eviscerator or filleter, and the possibilities of integrating digital cameras with processing machinery shows tremendous promise.

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