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Fish length measurements using artificial neural networks

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ABSTRACT

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An existing stereoscopic technique employing neural networks has been used to measure the length of fishes. Prior to the actual measurements, certain parameters that might affect the accuracy of the measurement were investigated. The influence of the index of refraction of water (depending on salinity) and the orientation of the object relative to the cameras on the accuracy of the measurement was examined.

Results showed that the salinity of water and the orientation of the object with respect to the cameras have negligible effect on the measurements. With a total error of less than 2 mm, the method presented in this paper is far better than conventional techniques.

Keywords: fish length, artificial neural networks, fish measurement accuracy

INTRODUCTION

Fishes play an important role as grazers in coral reef ecosystems for they can help in controlling algal growth in coral reefs (English *et al.*,1994). They are a staple source of protein for humans and various species provide recreation to sports fishermen. They are also commercially important for both aquaculture

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and tourism. Over the recent years, several fish populations (the total number of fishes in a certain category in terms of size, age or weight) have started to decline because of overexploitation and environmental deterioration. The population structure of fishes is highly dependent on the availability of food and the state of their environment, thus, accurate information on the size structure of a fish population, when linked with knowledge of the biology of the species, can allow analysis regarding fishing intensity, environmental impacts and rates of recovery (Shortis and Harvey, 1998).

Marine biologists often use the average length of a fish population to assess the abundance, and the size frequency of species populations and to determine the effects of environmental impacts on marine ecosystems (Shortis and Harvey, 1998). By obtaining the number of a particular species of fish, together with estimates of their length, the population size structure can be determined (English *et al.*, 1994). The most common method employed by marine biologists in estimating the length of fishes is the visual census technique. This technique utilizes minimum personnel and specialized equipment. It demands intensive training of divers doing the underwater measurements to get the best possible accuracy. The method has low statistical power to detect changes in size structure of rare species. Large inconsistencies in the length estimation of fishes also arise due to inter-observer variability. Shortis *et al.* (1998*)* found that the visual census technique gives rise to inaccurate results. They found errors in the length measurement of up to 30%. Aside from these disadvantages, this method is restricted to shallow depths due to decompression constraints. To improve the accuracy of length measurements and to overcome the problem of subjectivity, a more advanced system of measurement must be developed.

In earlier study (Orofeo *et al.*, 2001), the lengths of coral branches were measured with high accuracy using stereovision techniques and artificial neural networks. With the present potential of the method, it can be applied to measure the length of fishes with a much higher accuracy in comparison to the visual census technique.

The measurement on corals also revealed that several parameters. specifically, the index of refraction and the orientation of the object relative to the cameras, might affect the accuracy of the length measurements. It is well known that objects submerged in water appear to be larger due to the difference in index of refraction between air and water. Furthermore, there may be changes in the refractive index of water due to to the changes in the salinity. The influence of the salinity on the results was investigated by performing length measurements on an object submerged in water of different salinities. The orientation of the object with respect to the cameras is the second parameter that was investigated in detail. The length of an object will vary with angular orientation when viewed from one of the cameras. These two parameters were investigated since fishes swim at random orientations in waters of different salinities. The results obtained for these parameters were used in the assessment of the results for the actual lengths of fishes. Results obtained with the stereoscopic technique are then obtained when using a vernier caliper for the length measurement.

THEORY

The Artificial Neural Network is a computer program whose function mimics the human brain. Similar to the physiology of the human neuron, the artificial neuron (the basic unit of the artificial neural network) has an input node, connection weights, and an output node. The algorithm used to train the artificial neural network in a supervised manner is the error back propagation algorithm developed by Rumelhart, McClelland, and Williams (1986). This algorithm has succesfully been used to solve a wide variety of of problems and is based on the error correction rule (Haykin, 1994). The purpose of the error-correction rule is to let the response of the output neuron in the network approach the desired response (Schalkoff, 1989). With this algorithm, a set of training inputs and desired outputs is presented to the network. The network learns to map the presented inputs and outputs by giving the desired activation state of the desired output units for each presented state of input units. The input vector is then propagated forward to determine the output signal. The error signal is obtained by determining the difference between the actual output and the desired output and is then back propagated through the network. The learning process of the network is achieved by adjusting the coupling strengths used in the network so that the difference between the actual output state vector and the desired output state vector is minimized. Learning is repeated until the network produces an actual output that is close enough to the desired one.

METHODOLOGY

The set-up (Fig. 1) employs the same configuration used before which produced the optimal accuracy in the measurements on coral (Orofeo *et al.*, 2001; Violanda *et al.*, 2000). This set-up consists of a pair of CCD cameras (LCL-903HS, Watec America Corp., USA) mounted on a rod placed at an optimal distance from each other. Both cameras were oriented at an angle of 600 with respect to the rod connecting the two cameras. A NI-IMAQ interface was used in the image acquisition of the object by the pair of CCD cameras.

The network needs to be trained first in order to obtain the correct transformation of the two images. The training set (Figure 2) was composed of 192 data points, uniformly distributed over the volume of 40 x 40 x40 cubic centimeters whose center was 1m from the rod. In gathering the training data, a flat plane containing 32 light emitting diodes (LEDs) uniformly distributed over its surface was used. The plane was placed at 6 different positions parallel to the rod within the volume of the aquarium filled with water.

Prior to the actual measurement of the object, the network was trained with the training set submerged in fresh water. The optimum weights obtained when doing the training in fresh water were also used in carrying out the transformation to obtain the lengths of the object submerged in water at different salinities. As stated before, the apparent length of an object varies with the index of refraction of water. To measure the change in apparent length as a result of changes in the refractive index due to salinity, the length of an object was measured by submerging the object in the aquarium filled with water of different salinities. Various amounts of salt were added to the water inside the aquarium to attain a salty level range that covers the salinity of oceans and seas. A salinity meter (CD150 HACH Conductivity Meter Model 50150) was used to accurately measure the salt content of the water used.

The two endpoints of the object must be visible to both cameras. The projection of an object will vary with angular orientation when viewed from

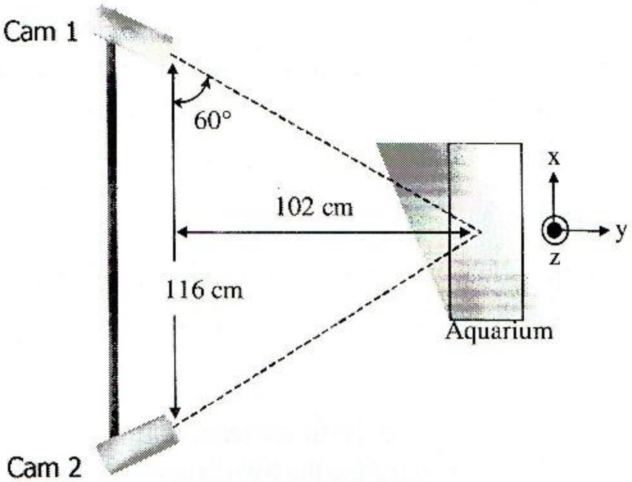


Figure 1. Top view of the set-up; the cameras are aligned on the x-y plane. The arrows indicate the direction of the coordinate axes with the z directed outward the page.

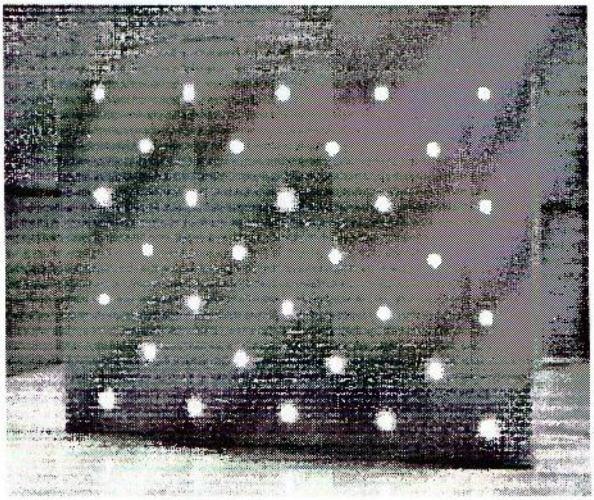


Figure 2. The training set is made of PVC material and consists of an array of 32 Light Emitting Diodes.

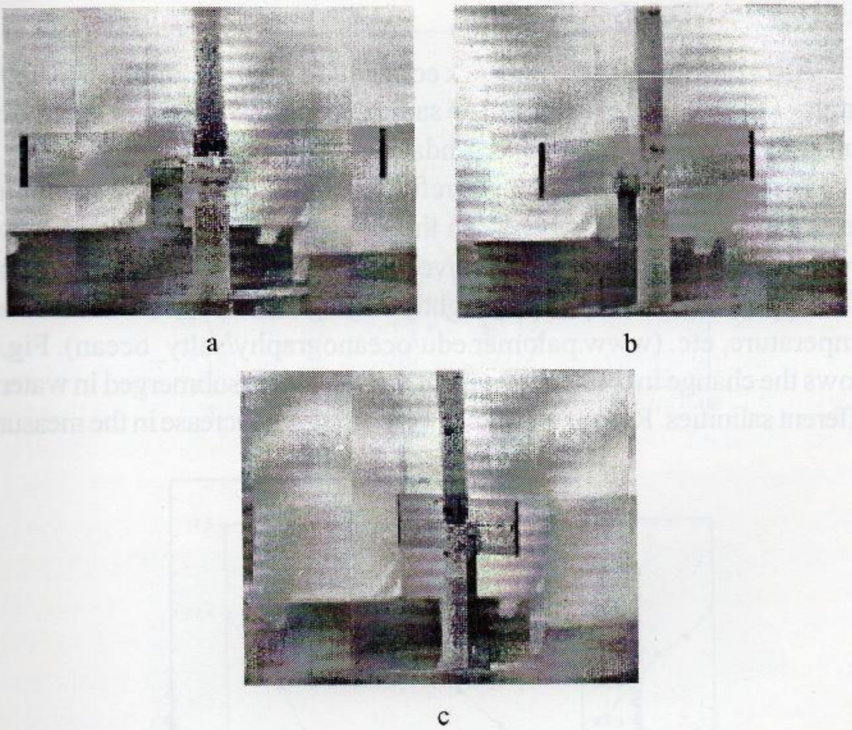


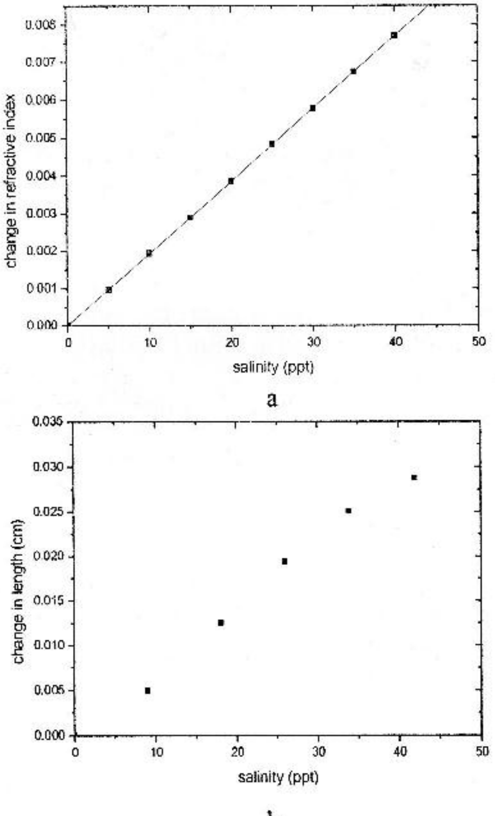
Figure 3. Different views of a ruler (immersed in water) placed at different angles as seen by a single CCD camera. The ruler placed at (a) 0°, (b) 30°, and (c) 90° with respect to the axis parallel to the rod joining the two cameras.

one of the cameras. If the object is perfectly in line with the optical axis of one of the cameras then that camera cannot distinguish between the endpoints. A configuration similar to the one shown in Fig. 3 was used to investigate the influence of the orientation of the object on the length measurement. An improvised device consisting of a ruler mounted on a protractor was used as an object. The ruler was placed at different angles between 00 and 1800 in steps at 10^0 with respect to the x-axis (parallel to the rod connecting the two cameras) and images of the ruler were obtained. Before the actual transformation, the images of the object underwent image processing, enhancement, and filtering using a set of functions built in the IMAQ Vision Builder and LabVIEW (Parker, 1995; National Instruments, 1999). Using the stereoscopic method, the length of the ruler was then determined from the images captured by the two CCD cameras.

RESULTS AND DISCUSSION

After the training, the network converted a total minimum error of 0.8 mm for all coordinates (x, y, z), the same accuracy as obtained in previous studies (Orofeo *et al.*, 2001; Violanda *et al.*, 2000).

Fig.4 shows the change in the refractive index of water as a function of the salinity. The graph is based on the data obtained by Dorsey (Dorsey, 1940). It is observed that the refractive index of water increases with salintiy of Philippine seas is about 35 ppt, slightly varying with factors such as location, temperature, etc. (www.palomar.edu/oceanography/salty_ocean). Fig.4b shows the change in the apparent length of the object submerged in water of different salinities. Results show that there is a slight increase in the measured



a

b

Figure 4. (a) Change in the refractive index of water as function of salinity. (b) Change in measured length of an object submerged in salt water as function of salinity. (ppt = parts per thousand)

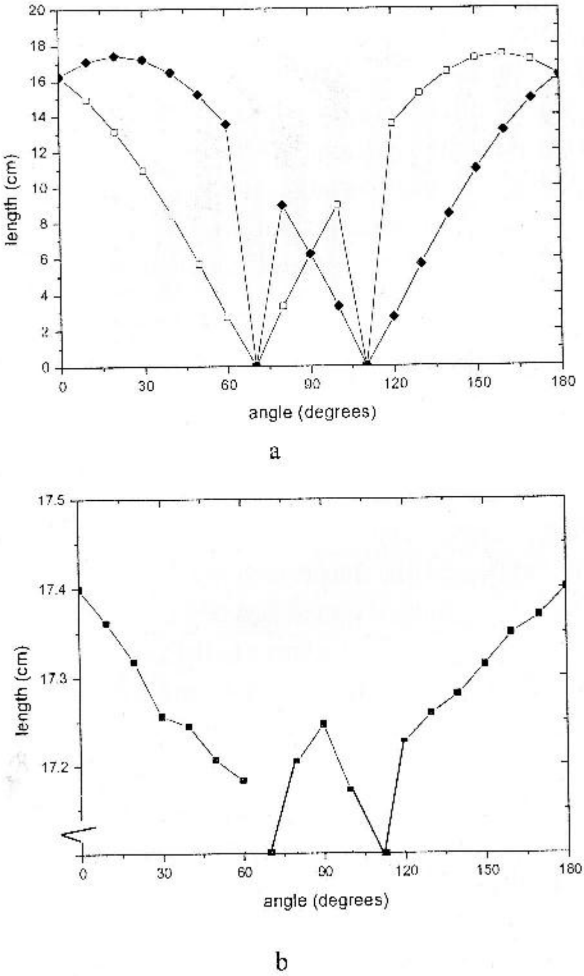


Figure 5. (a) The projection of the object as seen by camera 1(unfilled à) and camera 2 (filled") as function of the angle between the object and the x-axis. (b) The length of an object measured with the stereoscopic technique as a function of the orientation.

length of the object as the salinity of water increases. As can be seen from Fig. 4, both the changes in the length of the object and in the refractive index vary linearly with salinity. This shows that the change in the object's length and the change in the refractive index have a linear relation. However, the change in length due to the change in salinity is small (max 0.3 mm) compared to the minimum error due to the transformation (which is 0.8 mm for the three coordinates together). Therefore, the effect of changes in the salinity of the water is negligible.

To investigate the effect of the orientation of the object on its measured length, the projections of the object relative to each one of the two cameras were determined. These 2-D results are essential in predicting the outcome of the 3-D measurement. As described in the previous section, the CCD cameras were oriented at an angle of 600 with respect to the rod connecting the two cameras (x-axis). If an object were positioned at an angle of 600 with respect to the x-axis, it is expected that the projection relative to one of the cameras is zero. However, in this study, it was observed that this zero result was found with the object at an angle of 700 relative to the x-axis This can be attributed to the presence of a refractive interface that causes the light rays to bend in a slightly different direction (Hecht, 1990). A similar situation occurs at an angle of 1100 for the other camera. Shown in Fig. 5a is the two-dimensional length of the object as seen by both cameras individually. The length of the projection is largest at 200 as seen by camera 2 and at 1600 as seen by camera 1 because at those angles the object is perpendicular to the line of sight of cameras 2 and 1 respectively.

Using the stereoscopic method, the apparent length of the object was measured at different orientations. Fig. 5b shows the variation of the measured length as a function of the angle of orientation (angle between the object and the x-axis). At angles 700 and 1100, the measured length of the object is zero since the camera cannot distinguish between the endpoints. As seen from Figure 5, the two graphs representing 2D projection and the 3D length, respectively, have similar shape.This proves that the network has learned to perceive depth. Moreover, the variation in measured length with changing angle is less than 2 mm, the accuracy reported in a previous paper. These results show that the method is capable of measuring lengths of objects with

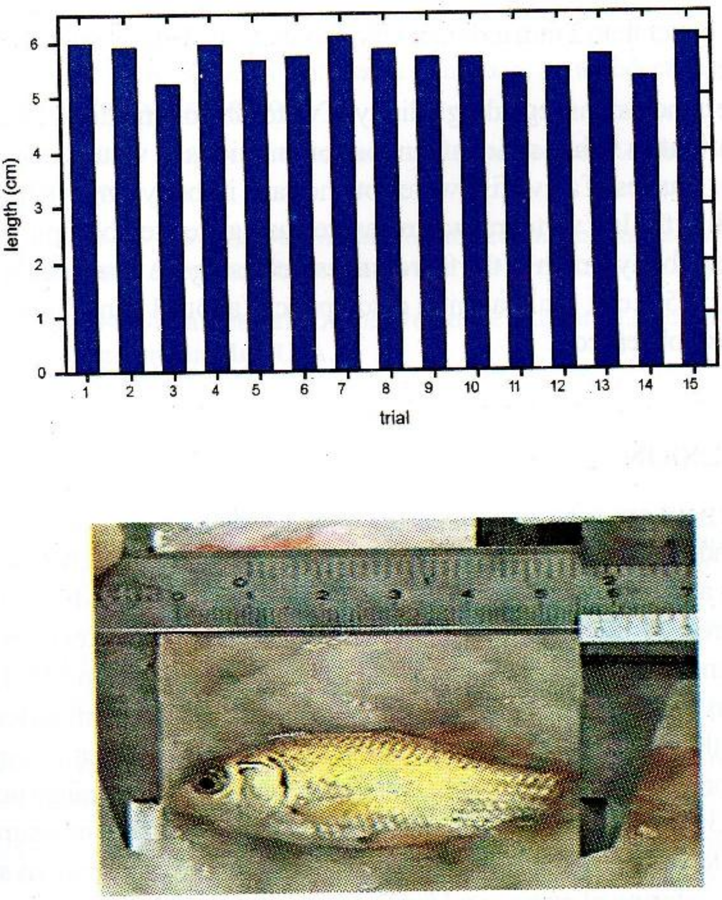


Figure 6. The body length of a live fish was obtained for a number of trials using the stereoscopic technique. The average length of the fish was found to be (5.7 ± 0.2) cm. The length of the fish measured using the vernier caliper is 5.8 cm, which exhibits a discrepancy of only about 1mm.

accuracy better than 2 mm as long as the cameras can distinguish between the endpoints.

The conclusions regarding salinity of water and orientation of the object are important as fishes swim at random orientations in waters of different salinities. Images of a live fish were obtained and its body length (from tip of the mouth to the last vertebra) was measured using the stereoscopic method. The average body length of the fish as measured using the vernier caliper was found to be 5.8 cm. Only a small discrepancy (about 1 mm) between the lengths was observed.

CONCLUSION

The network is capable of producing reliable results regardless of the salinity and the orientation of the object relative to the cameras. This method is therefore a good alternative to the visual census technique.Moreover, the accuracy reached by this method (error less than 4%) is far better than that of the conventional visual census technique (error range of 5% to 12%). Also, this method has an average deviation (precision) of less than 2 mm (less than 3%) from the length measured with a vernier caliper. This is far better compared to precisions observed with the visual census technique, which range between 10% and 30% of the length. Aside from this, accurate length measurement using this technique can also be helpful in other biological applications such as growth monitoring of marine and fresh-water organisms.

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