Fish Volume Monitoring Using Stereo Vision for Fish Farms

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Abstract: Aquaculture is an activity that is growing 10% a year in Brazil and still occupies less than 1% of the area reserved for fish farming, which shows the great productive potential of Brazil. With this growth, many challenges are emerging and many advances are being made. One technology they are starting to use in Brazilian fish farms is stereo cameras that can evaluate the average weight of Nile tilapia in a tank. This estimation of fish weight is based on its 3D length, but one of the most correlated information with the fish weight is its width. Thus, the objective of this work is to improve this estimation using stereo cameras by processing the cloud point of the surface of the fish. This paper shows some preliminary results that encourage further research since was obtained results similar to the methodology currently used.

Keywords: Nile tilapia weight, stereo vision, point cloud.

1. INTRODUCTION

Brazil has a very extensive water resources and coastline. Associated with its favorable weather, the aquaculture industry emerges as a very attractive economic activity. Nevertheless, the country uses less than 1% of its continental water reserves for fish production, being pointed as the only nation capable of competing the absolute world leader, China, in terms of production. Regionally, it is the agribusiness sector with the highest growth rate, with an average of 10% p.a on the last five years. Almost all fish farming in Brazil are located in continental waters, not in maritime waters. The fish ponds and the cage system are the two predominant production method, producing mainly the Nile tilapia.

One of the main challenges of this activity is the proper fish feed to its efficient growth, leading to a reduction of feed waste. Unlike the feed of terrestrial animals, the not eaten fish feed cannot be recovered, once it end up sinking. So, the excess of feed ends up generating both an economic waste and an environmental impact. One factor that makes this calculation complicated is the fact that the quality of the feed varies greatly. This variation is due to the change that factories make in their components to always keep its price as economical as possible considering the changes in the ingredients that can compose it. Another factor that makes the calculation of the exact amount of feed more difficult is the fact that farms cannot track how fish are growing throughout the production cycle. They could track fish growth by measuring 10% of fish weights inside a tank, however as each tank has a very high number of fish, it is hard to do this amount of measures and therefore they end up give up of this procedure because it usually gives inconsistent results.

To solve this problem of getting the average fish weight in a tank, several systems have already been developed and many offshore fish farms outside Brazil already use these systems to automate production. A research review on this subject can be seen at Hao et al. (2016). There are several studies that correlates various fish characteristics such as size, area and shape with its weight, and these relationships vary from species to species. Silva et al. (2015) show a relation between the Nile tilapia length and weight, Hockaday et al. (2000) show how a truss network can be used to estimate the Nile tilapia weight. Thus it is possible to use sensors that can extract this information and thus estimate the average fish weight inside a tank. Usually, the used sensors are sonar(Han et al. (2009)), cameras(Letessier et al. (2015)), infrared frames(Riveros (2017)), among others.

Some Brazilian cage fish farms are already starting to use this type of technology. The system that they are using is based on a stereo camera and the weight is estimated based on the fish's 3d length. But with a stereo camera, it is possible to extract a point cloud from the fish surface and so the aim of this research is to try to improve fish weight estimation from a stereo camera using a point cloud.

Compared to other ways to use sensors to fish weight estimation, few researches have already been done regarding the use of fish volume for this purpose. Some works on this subject are found trying to improve the efficiency of filleting machines, because these machines need to know the size quite precisely so as not to have a fillet waste. Mathiassen et al. (2011) use a camera and a laser to estimate the volume of the fish. However, the conditions, in which this system works under, are well controlled compared to the conditions of a fish farm (the fish are always perpendicular to the camera). Others researches do

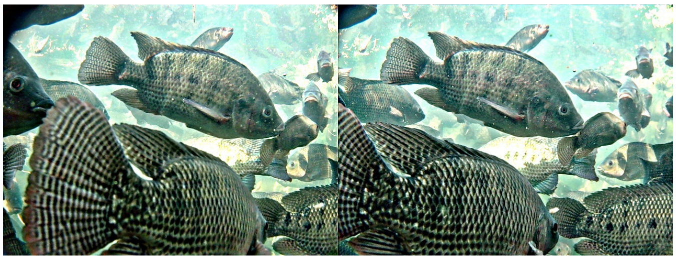

Fig. 1. Stereo image used to generate the point cloud of a Nile Tilapia.

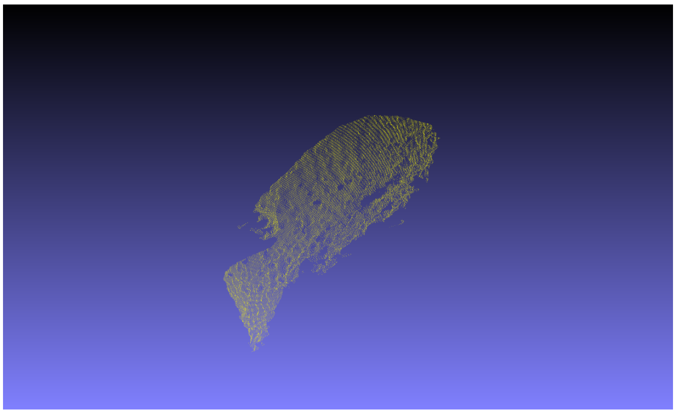

Fig. 2. Point Cloud of a Nile Tilapia from a fish farm.

not directly deal with fish weight estimation with volume, but they are the basis for the volume estimation. Risholm et al. (2018) develop a sensor to extract better point clouds from fish surface and Rzhanov and Cutter (2012) evaluate the best way to generate the disparity map from stereo cameras.

2. MOTIVATION

The motivation of this research came after being able to generate a point cloud from a stereo image obtained through a commercial equipment that is used to estimate the average weight of fish in a tank. Figure 1 shows the image used to generate the point cloud and figure 2 shows its point cloud.

This equipment consists of a camera and a electronic that records the images. The devise camera is a low cost USB 960P augmented reality camera that is housed in a specifically designed waterproof vessel. Figure 3 shows this equipment.

The equipment has two 9800mAh lithium-ion batteries that are enough to keep a raspberry pi zero W turned on taking pictures of the fish during the whole day. The tank in which the camera will take pictures is identified using a qr code. The image processing is not done in the embedded electronic; at the end of the day, the equipment is taken to a place with internet connection and the taken images are sent to a computer to processes them, extracting the 3D fish length to estimate its weight. This result is sent in the next day to the fish farmer.

Currently this commercial equipment uses only 3D fish lengths to estimate its weight, but as reported in Hockaday et al. (2000), the fish width is one of the most correlated

Fig. 3. The camera of the commercial system.

information to estimate its weight. Thus, the objective of this research is to try to improve this commercial system by processing the point cloud of the fish surface. Since the image is not processed in real time, the computational cost increase caused by processing a point cloud, does not make the procedure unfeasible. Using the point cloud will also improve the system by giving it more functionality, once it will be able to analyze aspects such as fillet yield and the presence of visceral fat.

3. METHODOLOGY

In this section it will be reported the developed process to estimate fish volume using the point cloud. A flowchart containing all the steps of the process in shown in the figure 4.

The first step of the process is to generate a point cloud of the fish's surface from the stereo image taken from the camera. Firstly, it is necessary to calibrate the stereo camera. The calibration process that will be used in this work is the one implemented in OPENCV library that uses a chessboard. Once the camera is calibrated, it is possible to rectified the images and generate the disparity map using the Semi-Global Block Matching (SGBM) algorithm implemented in the OPENCV library which is based on Hirschmuller (2008) work. The fish surface's point cloud is generated by the use of the disparity map and the camera calibration. Then from the point cloud it possible to run the algorithm presented by Mörwald (2012) to fit the point cloud on a surface. This algorithm can be split into 5 steps.

(1) Initialization of the B-spline surface
(2) Refinement and fitting of the B-spline surface
(3) Initialization of the B-spline curve
(4) Fitting of the B-spline curve
(5) Triangulation of the trimmed B-spline surface

In the first step, the algorithm starts by initialization of the B-spline surface by applying the principal component analysis (PCA), the PCA defines a plane in which a basic B-spline surface represents it as a starting solution. In the second step, the algorithm uses a modified squared-distance-minimization (SDM) to evaluate the distance between the cloud point and a B-spline surface, by solving a linear system the algorithm determined a set of control points that defines a B-spline surface that fit the surface

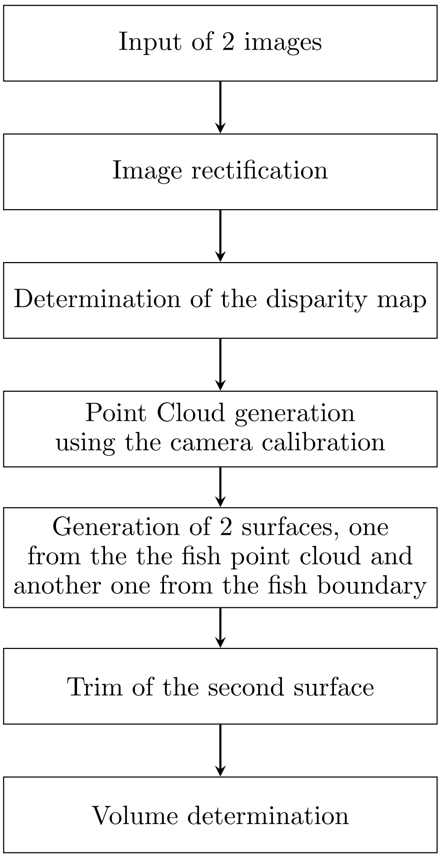

Fig. 4. Flowchart of the proposed methodology.

into the point cloud. In the third step, its initialize the curve that will be use to trimmed the surface. A PCA determines the center and a radius of a circumference that is close to the boundary points. The forth step uses a similar processes of the second step, in this step the algorithm determines a B-spline curve that approximates the boundary points. However, this approximation is not performed in the $R3$ domain, it is performed in the $R2$ domain. Firstly, it projects all boundary points in the fitting surface. So, instead of working in $R3$; x, y and z coordinates; it works with the surface parametric domain u and v. The determination of control points that fit a B-spline curve to the boundary points will result in a curve on the fitting surface. In the last step, the determined B-spline curve is used to trim the fitting surface, following a surface discretization to create a triangular mesh.

After all those steps the algorithm generates an open surface, and in the case of this work, it will be just the representation of half of the fish. Note that that algorithm just provide a open surface as output. If the algorithm provides a closed surface as output, the volume of half fish is computed simply by calculating the volume of the surface. So the next step is to close this surface. For this it will be necessary to first extract the contour of the fish surface by find all the edges of the surface triangulation that does not have neighboring triangles. Using the determined contour, the surface fitting algorithm is used to determine a surface that approximates the contour. Note that there are no points inside the contour leading to a smooth surface representing the back of the fish, that will close the first surface. Having this second surface, the next step is to trim it so it can match with the first one. To perform this step it was used the point polygon test. This algorithm is a simple way to determine weather a point is inside or outside a polygon by counting how many times a endless ray, starting at this point and with any fixed direction intersect with the contour of the polygon. If this count is even it means that the point is outside the polygon and if it is odd, the point is inside. Thus with this algorithm it was possible to trim the back fish surface with the front. So with this two surfaces, the next step is to calculate the volume of this new closed surface. The volume of this closed surface will be calculate using the divergence theorem which states that the calculation of this closed surface can be done by separately calculating the volume of each open surface and then subtracting one volume from the other. The volume of each open surfaces will be calculated by iterating over all the triangles that form the surface and calculating the area of the triangle and multiplying by the average z of the vertices of this triangle. After calculating the volume of these two surfaces, the volume of half the fish is calculated by subtracting one volume from the other.

4. DATA COLLECTION

The aim of this work is to verify the accuracy of using fish volume, obtained from a point cloud, to estimate the fish weight. To achieve this goal, it is necessary to validate the accuracy of the volume obtained from the point cloud with some ground truth data as well as find a equation that correlates the volume of the fish with its weight.

The data were collected using Nile tilapia of a commercial production farm called Água Pura Fish Farm, located in Santa Branca dam, in the state of São Paulo, Brazil. A cylindrical glass vase with 14 cm of diameter was used to collect the volume of the fish. The volume was calculated based on the change of the water column inside the cylindrical before and after putting the fish inside it. The fish pictures used to create the point cloud was taken using a commercial stereo camera, the Fujifilm Finepix real 3D. A weight scale with precision of 2g was used to collect the weight of the fish.

All the data was collected on the fish farm and the process was the following. First the fishes were taken out of the production tank and put on a box with anesthetizing outside the river. Then, after 5 minutes, the fishes were already anesthetized. And one by one, a fish was weighed, a picture of it was taken with the camera yet on the balance's plate and without any artificial light, and then it was placed on the cylinder to measure its volume. In the end, the fish is returned to the production tank. All this procedure was done with 52 fishes, the figure 5 shows the volume and weight measured data.

As the data collection involved live animals, one of the concerns was to perform a quick procedure to not affect the animals, and so only one photo of each fish was taken. Thus, only one side of each fish was photographed, which was enough to perform the tests of this work.

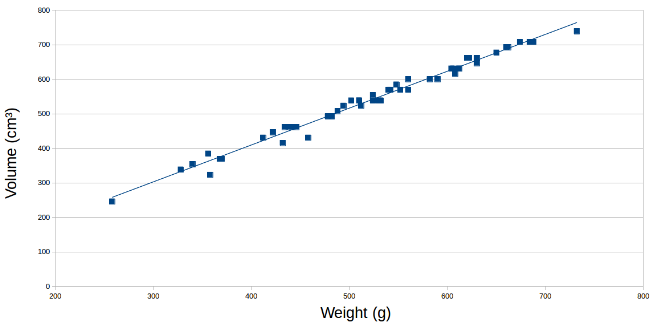

Fig. 5. Nile Tilapia Weight to volume ratio.

Fig. 6. Stereo image used as input to the algorithm.

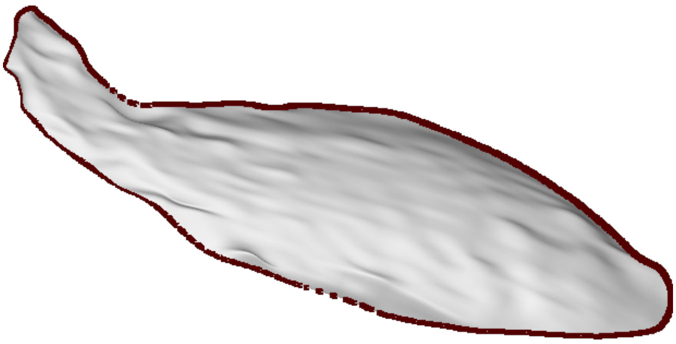

Fig. 7. Open surface of the front of the fish, the red points are the boundary points.

5. RESULTS

In this section, it will be presented the results obtained in this research. The first part of this section will show some of the algorithm outputs and then it will be discussed the estimated values of volume and weight by comparing them with the ground truth data. The images used as input data to the proposed algorithm were images taken from a stereo camera as the one shown in figure 6. A point cloud was generated from the stereo image, and it was used to generate a triangulated trimmed B-spline surface. An example of the generated open surfaces is shown in figure 7.

Note that in figure 7, the surface generated is an open surface and to calculate the volume of the fish it was necessary to have a closed solid. For that it was necessary to find the boundary of this surface by finding all the edges of the triangulation that did not have neighboring triangles, these points are shown in figure 7 marked with red points. A surface was fit with these boundary points, and it was trimmed using a point polygon test. A result is shown in figure 8.

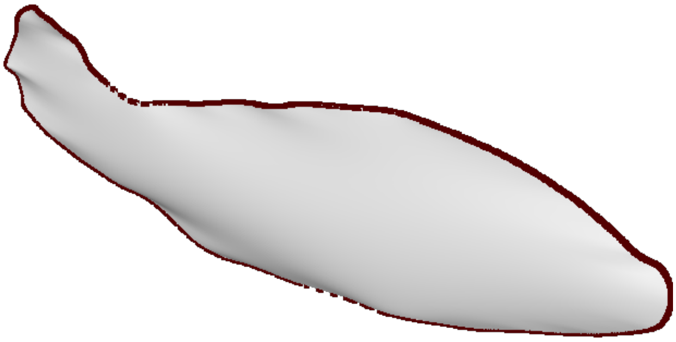

Fig. 8. Surface representing half of the fish's body, red points are the boundary points.

Once it was determined both surfaces that represents half of the fish's body, it was possible to calculate its volume using the divergence theorem. The results are shown in the table 1. As can be seen from the table 1, the volume estimation using the process described in this paper presented two results that had relatively low errors and another with a larger error. Discarding the third error, the methodology had an error of approximately of 4.55%, which is an encouraging indicator that a point cloud of the fish surface can be used to estimate its volume. The third result was discarded because in addition to its large error, another aspect had been observed. The obtained result is much smaller than the real value. This is not very coherent, once the algorithm used in this work does not try to figure out the symmetry plane of the fish. This work uses the preposition that the fish is on a straight plane and the photo was taken roughly perpendicular to that plane. The generated point cloud is close to the symmetry plane but not really in the symmetry plane. The adopted symmetry plane tends to be bellow the real symmetry plane, leading to an estimation greater than the real value. So, positive errors in the volume estimation were expected. Analyzing the stereo image used to generate the third result, was discovered that some aspects of the images were causing some failures on the match algorithm that generates the disparity map. These aspects are the sun's light reflection on the fish and the fact that some parts of the fish are monochrome. The figure 9 highlights these aspects. Due to these image aspects, some holes in the contour of the fish were generated and the surface of the fish was not well estimated.

The obtained results show that the methodology used to estimate fish surface is not so robust. One way to overcome this problem is to use an a priori raised average surface of a set of fish as a guide for the surface fitting. An example of the methodology that can be used to fix this error is found in Tytgat et al. (2012).

Table 1. Volume result.

Fish	Measured Volume (cm^3)	Estimated Volume (cm^3)	Error (cm^3)
1	338.66	356.02	17.36 (5.12%)
2	569.57	608.40	38.83 (6,81%)
3	369.45	328.70	40.75 (11.03%)

One of the objectives of this work is to estimate the weight of the fish through its volume, next also will be show the results of this estimate. With the motivation to evaluate the quality of the obtained results, the result of estimating

Fig. 9. Image characteristics that have confused the stereo match algorithm to create the disparity map (sunlight reflection on the fish and monochrome areas)

the weight using the length of the fish will also be shown since this is currently the method used. To estimate the weight using the volume was used the equation found in section 4 and to estimate the weight using the length was used the formula found in Silva et al. (2015) that is $weight = 0.0203 * length^{3.0604}$. The results are shown in the tables 2 and 3.

Table 2. Weight result.

Fish	Measured Weight (g)	Weight from Length (g)	Weight from Volume (g)
1	328	314.84	352.18
2	540	455.84	585.00
3	370	325.91	326.98

Table 3. Error of weight result.

Fish	Error from Length (g)	Error from Volume (g)
1	13.16 (4.01%)	24.18 (7.37%)
2	84.16 (15.58%)	45 (8.33%)
3	44.09 (11.91%)	43.02 (11.63%)

As can be seen from the tables 2 and 3, the estimates from the volume gave results near from the estimates from the length. Disregarding the result of the third fish, as done before, the estimates from the volume presents an average error of 7.85% while from length presents an error of 9.79%. These results also show that even with a large error on the estimation of the volume of the third fish, the error in the weight was not so high. In conclusion, although only a few results was been evaluated, they show the feasibility of the study proposed.

6. CONCLUSION

This paper shows that is possible to estimate the volume of the fish with some precision using the point cloud generated by a stereo camera and also that it is possible to estimate the weight of the fish using this volume. These result encourage further research in this subject since was obtained results with near accuracy of the methodology currently used. The next steps are to improve the algorithm by using a prior surface as a guide to the surface fitting and by trying to find the symmetric plane and to start to generate results using underwater stereo images.

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