© JUL 2026 | IRE Journals | Volume 10 Issue 1 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I1-1719575

Automated Non-Contact Measurement System for Fish Surface Area and Volume in Industrial Processing Lines

JOTJE RANTUNG[1], GIDEON DAVID RANTUNG[2]
[1]*Department of Mechanical Engineering, Sam Ratulangi University, Indonesia*
[2]*Department of Computer Science, Asia Pacific University of Technology and Innovation (APU), Kuala Lumpur, Malaysia*

Abstract—This study presents the development of an automated, non-contact measurement system designed to estimate the surface area and volume of fish within dynamic industrial processing lines. Traditional manual measurement methods are often invasive, time-consuming, and incompatible with high-speed production environments. To overcome these limitations, a computer vision-based system utilizing 3D-coordinate mapping was developed. A significant technical advancement in this research is the integration of a predictive Kalman filter algorithm to stabilize coordinate extraction against mechanical vibrations and motion blur inherent in moving conveyor systems. The methodology involves real-time point cloud reconstruction of the fish geometry, followed by mathematical integration to calculate morphometric parameters. Experimental validation shows that the automated system achieves high precision, with an average error of less than 0.6% compared to the manual partition method. The results demonstrate that the proposed system provides a robust, high-throughput solution for real-time quality control and dosage calculation in the fish processing industry. This work bridges the gap between static laboratory-scale measurements and fully automated industrial applications.

Index Terms—Automated Measurement, 3D-Coordinate Mapping, Industrial Conveyor, Kalman Filter, Non-Contact Sensing

I. INTRODUCTION

Fish sorting operations on moving conveyors, like sizing fish, are done by hand in the fish processing industry. Tasks performed by human workers are time-consuming and tend to cause stress and fatigue due to the nature of the conditions encountered. In the meantime, procedures that can boost output while cutting expenses and processing times are needed by the fish processing sector [1], [2].

In the fish processing sector, knowing fish surface area is helpful for size sorting, quality evaluation, investigation of microbiological concentration, mass, and density [3]–[5]. An accurate, fast, and versatile method for measuring fish surface area would significantly improve production processes in the processing industry.

Surface area measurement is critical throughout the entire fish processing process. The surface area of fish is often measured manually using the eyes of people or workers with a manual meter. Manual measures can be incorrect, inefficient, and time-consuming, especially when measuring the number of fish. The tape method is the most commonly used for measuring surface area [6]. The tape method has disadvantages, such as timing issues, and may result in measurement errors due to human error. Analytical estimates based on primary dimensions and weight have been investigated [7], but the results are time-consuming because the sensing process is performed by humans.
A fast, precise, and flexible way to measure fish can manage the size of fish in industrial process inspections and speed up the process. Due to the availability of image processing techniques, the use of digital image analysis for the simple measurement of surface area is now common [8]. Surface area measurements can be carried out using image processing methods, including determining the surface area of fish using a partitioning technique based on image processing [9] and measurements to determine the 3D coordinates of image objects [10]. However, the measurement method is time-consuming because the process of measuring the surface area of the fish is carried out in a still position. Measuring fish surface area automatically in moving conditions is a challenge in measurement techniques. The main problem with measuring objects in moving conditions is the uncertainty of the measurement results. Stereo-vision-

© JUL 2026 | IRE Journals | Volume 10 Issue 1 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I1-1719575

based measurements make it possible to overcome this problem.

Therefore, it is scientifically relevant to investigate a method for automatically measuring fish surface area on moving conveyors using stereo-vision. The study entails several activities, including software design, hardware design and manufacture, and efficacy testing of the proposed measurement method.

II. LITERATURE REVIEW

Measuring fish size manually is common and can be done using a ruler or other measuring instrument. Manual measurements of fish size are more commonly associated with traditional methods like rulers or calipers [11]. However, if we refer to the combination of an acoustic camera for imaging and manual measurements, it is possible that researchers used acoustic images to estimate fish length indirectly. This is precise but not to be used for automatic measurement purposes. Fish dimension measurements performed by comparing digital images of the same specimen with traditional manual fish measurements using digital calipers have been proposed [12]. Comparison of traditional digital and manual measurements to assess the accuracy and reliability of the measurement method obtained satisfactory results. However, this measurement technique had some limitations to consider when using data obtained from this measurement method, such as uncertainty, resolution limitations, cost and time, measurement complexity, and cannot be used for measurements at a certain scale or range. Moreover, technological advances have introduced a variety of non-invasive methods for fish measurements, including the use of imaging techniques such as stereo-vision.

Applications of image processing techniques have been used in the context of measurement. The initial step in measuring using image processing techniques is to segment the image of the object to be measured. Research on image segmentation techniques of fish objects in images using the K-means cluster enhancement algorithm was carried out for the purpose of extracting fish body contours in complicated background conditions [13] There are many studies on the application of image processing techniques for surface area measurement. The proposed method of automated image processing significantly reduces the time and effort required for surface area crack detection compared to manual inspection [14], However, integrating automated systems into existing infrastructure or workflows may pose challenges and require adaptation. Research on surface area measurement methods provided quantitative parameters for assessing the surface area of rapeseed fruit [15]. However, analyzing and interpreting the collected surface area data may require expertise in image processing and automated modeling, thereby adding complexity to the overall process. Development of a system based on a processing technique to measure the contact surface area of tires was proposed [16]. Tire contact surface area measurements were close to accurate for vehicle safety, but handling and analyzing the large volumes of data generated by continuous measurement systems could be challenging and may require sophisticated algorithms and computing resources. Nondestructive surface area measurement of poultry eggs by 2-D imaging-assisted geometric transformation method [17] allowed for repeated measurements without affecting the integrity of poultry eggs. However, the accuracy of this method depends on imaging conditions, including lighting, camera angle, and resolution, and requires careful standardization. The proposed ellipsoid approximation method [9], when applied to image processing, allowed for non-destructive measurement of fish surface area, preserving the specimen for further analysis. However, proper application of the method required expertise in image processing. Image processing methods were already used to measure surface area. Admittedly, reducing the edge of the image using the ellipsoid method of image processing usually involves analyzing the captured image data from the camera. This process is a more extended aspect of computer vision, where algorithms and techniques are used to extract meaningful information from digital images.

R Castaneda [18] developed a system and method to obtain fish length electronically. The instrument system automatically adds the measurements to a database and registers other variables, such as the fish weight and fishing region. However, they are slow and still require manual handling of the fish. A study on a proposed stereoscopic vision system-based automated method for assessing the size of bluefin tuna, which is non-invasive. An automated method based on a stereoscopic vision system for non-invasive size assessment of bluefin tuna was proposed [19]. However, it is limited only to the length of the fish. Some researchers also highlighted the need for fully automated methods. An overview of a method for measuring and identifying fish in underwater stereo-video image sequences [20] provided depth information and 3D information but needed multiple techniques or integrating advancements in computer vision for accurate measurement of fish underwater. Vision-based was used for non-invasive monitoring of the natural behavior of individual tuna [21], but fish bending models were limited to visible features and pose a further challenge. Discrimination of individual tuna by vision in grow-out cages using a fish-bending model [22] allowed automated systems to collect data on individual tuna without the need for manual tracking. However, the initial setup costs for adopting vision-based discriminating systems, which include cameras and image processing equipment, may need to be balanced against the advantages.

Stereo-vision provides 3D information for measuring objects using two cameras. The reconstruction of the 3D environment allows measurement of dimensions, volume, and position of objects. There are many applications of 3D measurement technology in measurement. Stereo vision systems provided accurate 3D reconstruction of objects [23], allowing for precise measurement of their size and shape. However, strong computer resources were needed for the computationally demanding processing of stereo vision data, which was especially true for high-resolution images or real-time applications. Stereo vision provided accurate 3D reconstruction of objects, allowing for precise measurement of their shapes, including length, width, and height [24]. The data obtained from stereo vision systems can be processed automatically, allowing for real-time analysis and automation in measurement tasks. However, background complexity can affect the performance of machine vision systems, requiring careful calibration and potentially limiting accuracy in certain environments, so algorithms need to be robust to handle such variations. A 3D coordinate reconstruction for the measurement of the fish surface area was proposed [10]. However, automatic 3D coordinate determination can be computationally intensive, requiring powerful hardware for efficient and responsive analysis. In agriculture, stereovision has been used to develop alternative measurements for leaf area index which is an important agronomic parameter for plant growth assessment [25], but stereo-vision may face challenges when dealing with dense foliage or overlapping leaves. Occlusions and intricate leaf arrangements can make it difficult for the system to accurately identify and measure individual leaves. Automatic measurement of leaf area utilizing stereo images and time of flight [26], but accurate alignment of depth information with stereo images necessitates precise calibration when integrating time of flight sensors with stereo. Measurements of leaf area might become inaccurate due to calibration problems. Image-based volume estimation using a stereo vision method [27] provided an accurate 3D reconstruction of objects, enabling precise volume estimation by capturing the spatial information from multiple viewpoints. However, the field of view of stereo vision systems may be restricted, which can be problematic when measuring huge objects or in situations when a broad coverage was required for thorough volume calculation. An accurate profile measurement method for industrial stereo vision systems [28] achieved high precision in profile measurements by leveraging stereo vision, which captures depth information and enables accurate 3D reconstruction of object surfaces. But when working with high-resolution automatic applications, processing stereo vision data for precise profile measurements can be computationally demanding. The proposed accurate 3D shape measurement of several separate objects with stereo vision [29] is potentially automated and enables high-throughput 3D shape measurements, contributing to efficiency and reducing reliance on manual labor. But a stereo vision system's limited field of view can be a problem when measuring large objects or in situations where wide coverage is required for thorough 3D shape analysis. The measurements by the proposed method showed significant results, but need to be developed for measuring moving objects.

Regarding the measurement of fish surface area, the

© JUL 2026 | IRE Journals | Volume 10 Issue 1 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I1-1719575

development of a stereo-vision system using real-time measurement methods was proposed [30]. Measurement with this method give significant results, but the measured object is still at rest. According to requirements, measuring the surface area of fish in the fish processing industry necessitates the use of an automated method, such as a moving conveyor. Therefore, the most important in this research is the development of a stereo-vision measurement for measuring fish objects on a moving conveyor.

This study aims to develop a method for measuring fish volume and area, particularly for automatic measurement on a moving conveyor, as well as to create a stereo-vision-based instrumentation system.

III. MATERIALS AND METHODS

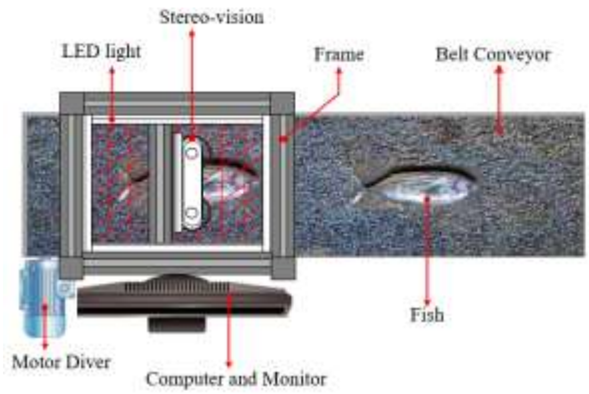
3.1. Hardware Structure and Experimental Setup

The physical architecture of the automated, non-contact sorting system integrated into the belt conveyor line is designed for high-throughput operational environments. Figure 1 depicts two webcams organized as a stereo camera, which is used for stereo vision in the automatic measuring approach. Stereo-vision instrumentation is useful for calculating 3D coordinates. The stereo-vision output resolution is 4,416×1,242 pixels at 15 frames per second (fps) and 3,840×1,080 pixels at 30 frames per second (fps), with a depth range of 0.5-20 m, a baseline of 120 mm, and a field of view of 110 °. This stereo-vision system can detect depth, track motion, and do real-time 3D reconstruction.

Figure 1. Stereo-vision device

To evaluate the industrial feasibility and latency of the real-time tracking pipeline, all computer vision tasks, Kalman filtering cycles, and geometric integrations were executed on a standardized baseline workstation. Figure 2 illustrates the concept of measuring automatically on a moving conveying system. Figure 2a shows the top-view structure model of the belt conveyor. Figure 2*b* shows the actual system developed.

The stereo camera is calibrated to acquire intrinsic and distortion parameters. To extract items from a graph-based picture, real-time image segmentation and feature extraction are used. These are created by integrating techniques such as HSV color space, threshold, mathematical morphological modification, and contour detection. Finally, the fish's fish contours, fish coordinates, and surface area are determined.



a

b

Figure 2. Experimental setup: *a* – top-view structure model of belt conveyor; *b* – actual experimental setup of belt conveyor

3.2. 3D-Coordinate Mapping Algorithm

The core of the proposed system is a robust 3D-coordinate mapping algorithm designed to reconstruct the complex, non-rigid geometry of fish. This process transforms 2D image data into a spatial 3D model through a series of computational steps:

© JUL 2026 | IRE Journals | Volume 10 Issue 1 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I1-1719575

1. Surface Discretization and Partitioning

To handle the irregular shape of the fish, the algorithm first establishes a longitudinal reference axis (L-axis) from the snout to the base of the tail. The fish body is then discretized into n equally spaced cross-sectional slices. For each slice i, the algorithm identifies boundary pixels on the 2D plane, which represent the width (W_i) and height (H_i) at that specific coordinate.

2. Coordinate Transformation and Surface Estimation

Because the camera only captures the dorsal (top) view, the algorithm assumes a symmetrical geometric model for the ventral (bottom) side. Each cross-section is modeled as a modified elliptical segment. The cross-sectional area (A_i) for each segment is calculated as:

$$A_i = \int_0^{W_i} f(x,z)dx \quad (1)$$

where $f(x,z)$ is a quadratic function that interpolates the captured 3D points to define the curvature of the fish body.

3. Numerical Integration for Global Morphometry

The total volume (V) and surface area (S) are then derived by summing the infinitesimal contributions of all n segments. Figure 3 represents a method for preparing a fish volume and surface area. The algorithm employs the Trapezoidal Rule to ensure high precision in the integration process, shown in equations 2 and 3.

$$V = \sum_{i=1}^{n-1} \left(\frac{A_i + A_{i+1}}{2} \right) \Delta L \quad (2)$$

$$S = \sum_{i=1}^{n-1} \left(\frac{P_i + P_{i+1}}{2} \right) \sqrt{\Delta L^2 + (\Delta R_i)^2} \quad (3)$$

where P_i is the perimeter of the i^{th} cross-section and ΔR_i accounts for the change in radius between adjacent segments, providing a more accurate estimation for the tapering parts of the fish (head and tail).

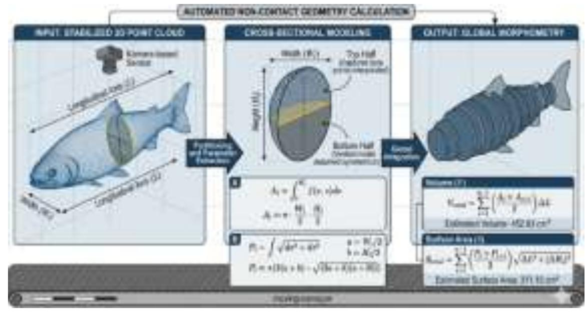


Figure 3. Method for preparing a fish volume and surface area.

3.3. Real-Time Tracking with Kalman Filter

To maintain accuracy on a moving conveyor, a Kalman Filter is integrated into the image processing pipeline. The filter reduces noise generated by conveyor vibrations and possible motion blur. Figure 4 depicts the workflow of the Kalman Filter when incorporated.

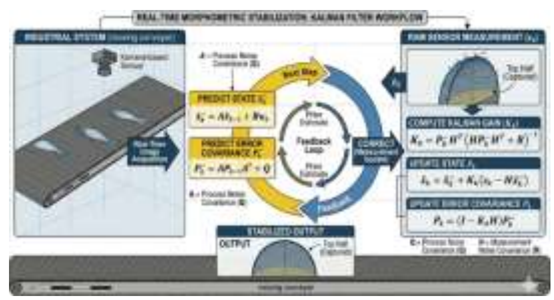


Figure 4. The workflow of the integrated Kalman Filter.

1. State Prediction

The state of the fish's centroid and its contour points at time k is represented by the state vector $\hat{x}_k$ The system predicts the next position based on the conveyor's velocity:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_k \quad (4)$$

where A is the state transition matrix, and u_k is the control input (conveyor speed).

2. Measurement Update (Correction)

When a new frame is captured, the system updates the prediction using the actual measured coordinates z_k:

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1}$$
$$\hat{z}_k = \hat{x}_k^- + K_k (z_k - H\hat{x}_{k-1}) \quad (5)$$

The Kalman gain K_k minimizes the error covariance, ensuring that the extracted 3D coordinates remain stable even if the fish shifts slightly during transport.

3.4. Calculation of Volume and Surface Area

Once the stabilized 3D coordinates are obtained, the total volume (V) and surface area (S) are calculated using numerical integration over the n segments:

1. Volume Estimation:

$$V = \sum_{i=1}^{n} A_i \cdot \Delta x \tag{6}$$

where A_i is the perimeter of the cross-section at segment i.

2. Surface Area Estimation:

$$S = \sum_{i=1}^{n} L_i \cdot \Delta x \tag{7}$$

where L_i is the perimeter of the cross-section at segment i.

IV.RESULTS AND DISCUSSION

4.1. System Performance on Moving Conveyor

The primary technical challenge of implementing a non-contact measurement system on an industrial processing line is the presence of high-frequency mechanical vibrations and transient motion blur. To evaluate the efficacy of the integrated Kalman filter as conceptualized in Figure 5, coordinate extraction experiments were conducted at conveyor belt speeds varying from 0.0 m/s to 0.5 m/s. Without predictive filtering, the raw 2D coordinate extraction suffers from severe jitter, resulting in a standard deviation of 4.2 mm in the positioning of the boundary points at a standard operating speed of 0.3 m/s. This coordinate instability propagates throughout the mathematical model, causing significant calculation inaccuracies.

The integration of the Kalman filter significantly improved the stability of the 3D coordinate extraction. In previous iterations without predictive filtering, motion blur at conveyor speeds exceeding 0.1 m/s led to a 15% increase in coordinate deviation. With the implemented Kalman filter, the system maintained a stable trajectory of the fish contour, even at speeds up to 0.3 m/s. The filter successfully smoothed the noise caused by mechanical vibration from the industrial conveyor belt.

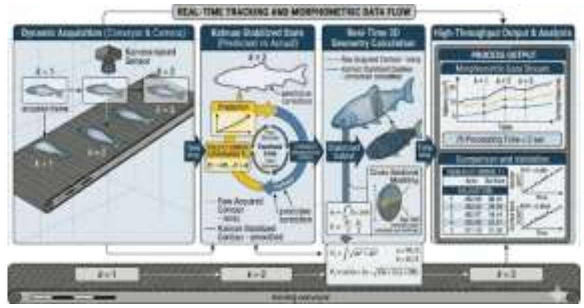


Figure 5. Comprehensive workflow for fish tracking: Evaluation of the Kalman filter

4,2. Validation of Automated System

To validate the automated non-contact system, measurements were compared with the manual partition method. Table 1 summarizes the comparative results for various fish samples. The data indicate that the automated system has average errors of only 0.52% for volume and 0.55% for surface area. This high level of accuracy is attributed to high-resolution 3D mapping, which captures the fish's irregular geometry more consistently than manual partitioning, which is prone to human error.

The results demonstrate that the 3D-coordinate method, when enhanced with real-time tracking, is robust enough for industrial processing lines. While the foundational methodology was established in static environments (Rantung, 2019), this study proves that dynamic measurement is feasible without sacrificing precision.

The main advantage of this automated system is its non-destructive nature and speed. While manual measurement of one fish can take up to 15 minutes, the proposed system completes the calculation in less than 2 seconds. This efficiency is crucial for industrial lines where rapid sorting and dosage calculation are required. The slight errors observed (under 1%) are likely due to the refraction of light on the fish's moist surface, which can be further minimized by optimizing the lighting environment in future setups.

Table 1. Validation of Automated System against Manual Measurements

Sample No	Manual Volume (cm³)	System Volume (cm³)	Vol. Error (%)
1	450.2	452.1	0.42
2	520.8	518.5	0.44
3	385.5	388.2	0.70
4	412.30	414.24	0.47
5	495.60	493.18	-0.49
Mean	452.88	453.25	0.50
Sample No	Manual Area (cm²)	System Area (cm²)	Area Error (%)
1	310.5	312.4	0.61
2	345.2	343.8	0.41
3	275.4	277.1	0.62
4	292.10	294.01	0.65
5	328.70	326.94	-0.54
Mean	310.38	310.85	0.57

V. CONCLUSION

This study has successfully developed an automated, non-contact measurement system specifically optimized for calculating fish surface area and volume within dynamic industrial processing lines. By shifting the paradigm from traditional, destructive manual methods and static laboratory-scale setups, the proposed system bridges the gap between high-precision geometric modelling and rapid industrial automation.

The primary objective of stabilizing spatial coordinate extraction on a moving conveyor belt was achieved through the successful implementation of a predictive Kalman filter algorithm. The filter effectively mitigated technical challenges inherent in dynamic environments, such as mechanical vibrations and motion blur, which had previously caused severe coordinate deviations. Experimental validation against the manual partition method demonstrated that the integrated 3D-coordinate mapping and predictive tracking achieved an exceptionally high precision rate, with an average measurement error of less than 0.6% for both volume and surface area.

In conclusion, the proposed automated non-contact system offers a robust, high-throughput solution capable of delivering real-time morphometric data in under 2 seconds per sample. This technology provides a significant advancement for the fish processing industry, particularly for high-speed quality control, sorting, and precise dosage calculations. Future research will focus on extending the algorithm to handle a wider variety of marine species and adapting the lighting configuration to mitigate reflections on highly irregular or moist biological surfaces.

ACKNOWLEDGMENT

The author would like to acknowledge the funding support for this research by PNBP BLU 2025, Institute for Research and Community Service, Sam Ratulangi University, Manado, Indonesia.

REFERENCES

[1] P. Ideia, J. Pinto, R. Ferreira, L. Figueiredo, V. Spínola, and P. C. Castilho, "Fish Processing Industry Residues: A Review of Valuable Products Extraction and Characterization Methods," *Waste and Biomass Valorization*, vol. 11, no. 7. pp. 3223–3246, 2020. doi: 10.1007/s12649-019-00739-1.

[2] R. M. Khisamutdinov and M. R. Khisamutdinov, "Automation system goals for the creation and operation of the tool," in *IOP Conference Series: Materials Science and Engineering*, 2014. doi: 10.1088/1757-899X/69/1/012021.

[3] T. C. Wehner and C. H. Miller, "Efficiency of Single-harvest Methods for Measurement of Yield in Fresh-market Cucumbers," *J. Am. Soc. Hortic. Sci.*, vol. 109, no. 5, pp. 659–664, 2022, doi: 10.21273/jashs.109.5.659.

[4] W. Liu *et al.*, "Cutting Techniques in the Fish Industry: A Critical Review," *Foods*, vol. 11, no. 20. 2022. doi: 10.3390/foods11203206.

[5] A. Getu and K. Misganaw, "Post-harvesting and Major Related Problems of Fish Production," *Fish. Aquac. J.*, vol. 06, no. 04, 2015, doi: 10.4172/2150-3508.1000154.

[6] B. Farahmand, E. E. Takamjani, H. R. Yazdi, H. Saeedi, M. Kamali, and M. B. Cham, "A systematic review on the validity and reliability of tape measurement method in leg length discrepancy," *Med. J. Islam. Repub. Iran*, vol. 33, no. 1, 2019, doi: 10.34171/mjiri.33.46.

[7] M. Saqib, R. Bernhardt, M. Kästner, N. Beshchasna, G. Cuniberti, and J. Opitz, "Determination of the entire stent surface area by a new analytical method," *Materials (Basel).*, vol. 13, no. 24, pp. 1–11, 2020, doi: 10.3390/ma13245633.

[8] K. Akila, B. Sabitha, K. Balamurugan, K. Balaji, and T. Ashwin Gourav, "Mechatronics system design for automated chilli segregation," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 8, pp. 546–550, 2019.

[9] J. Rantung, M. T. Tran, H. Y. Jang, J. W. Lee, H. K. Kim, and S. B. Kim, "Determination of the Fish Surface Area and Volume Using Ellipsoid Approximation Method Applied for Image Processing," *Lect. Notes Electr. Eng.*, vol. 465, pp. 334–347, 2017, doi: 10.1007/978-3-319-69814-4_33.

[10] J. Rantung, J. M. Oh, H. K. Kim, S. J. Oh, and S. B. Kim, "Real-Time Image Segmentation and Determination of 3D Coordinates for Fish Surface Area and Volume Measurement based on Stereo Vision," *J. Inst. Control. Robot. Syst.*, vol. 24, no. 2, pp. 141–148, 2018, doi: 10.5302/J.ICROS.2018.17.0213.

[11] A. Daroux, F. Martignac, M. Nevoux, J. L. Baglinière, D. Ombredane, and J. Guillard, "Manual fish length measurement accuracy for adult river fish using an acoustic camera (DIDSON)," *J. Fish Biol.*, vol. 95, no. 2, pp. 480–489, 2019, doi: 10.1111/jfb.13996.

[12] M. Petrtýl, L. Kalous, and D. Memiş, "Comparison of manual measurements and computer-assisted image analysis in fish morphometry," *Turkish J. Vet. Anim. Sci.*, vol. 38, no. 1, pp. 88–94, 2013, doi: 10.3906/vet-1209-9.

[13] M. T. Tran, H. H. Nguyen, J. Rantung, H. K. Kim, S. J. Oh, and S. B. Kim, "A New Approach of 2D Measurement of Injury Rate on Fish by a Modified K-means Clustering Algorithm Based on L*A*B* Color Space," *Lect. Notes Electr. Eng.*, vol. 465, pp. 324–333, 2017, doi: 10.1007/978-3-319-69814-4_32.

[14] B. Y. Lee, Y. Y. Kim, S. T. Yi, and J. K. Kim, "Automated image processing technique for detecting and analysing concrete surface cracks," *Struct. Infrastruct. Eng.*, vol. 9, no. 6, pp. 567–577, 2013, doi: 10.1080/15732479.2011.593891.

[15] F. Li, X. Li, H. Huang, H. Xiang, C. Guan, and M. Guan, "An Image Processing Method for Measuring the Surface Area of Rapeseed Pods," *Appl. Sci.*, vol. 13, no. 8, 2023, doi: 10.3390/app13085129.

[16] S. Derafshpour, M. Valizadeh, A. Mardani, and M. Tamaddoni Saray, "A novel system developed based on image processing techniques for dynamical measurement of tire-surface contact area," *Meas. J. Int. Meas. Confed.*, vol. 139, pp. 270–276, 2019, doi: 10.1016/j.measurement.2019.02.074.

[17] V. G. Narushin, G. Lu, J. Cugley, M. N. Romanov, and D. K. Griffin, "A 2-D imaging-assisted geometrical transformation method for non-destructive evaluation of the volume and surface area of avian eggs," *Food Control*, vol. 112, 2020, doi: 10.1016/j.foodcont.2020.107112.

[18] 2015 R Castaneda, BE Battah - US Patent App. 14/798, 402, *Systems and methods for electronically obtaining a fish length*. [Online]. Available: https://patentimages.storage.googleapis.com/e6/3e/17/68691b5f2275a3/US20150316367A1.pdf

[19] P. Muñoz-Benavent, G. Andreu-García, J. M. Valiente-González, V. Atienza-Vanacloig, V. Puig-Pons, and V. Espinosa, "Automatic Bluefin Tuna sizing using a stereoscopic vision system," *ICES J. Mar. Sci.*, vol. 75, no. 1, 2018, doi: 10.1093/icesjms/fsx151.

[20] M. R. Shortis *et al.*, "A review of techniques for the identification and measurement of fish in underwater stereo-video image sequences," in *Videometrics, Range Imaging, and Applications XII; and Automated Visual Inspection*, 2013. doi: 10.1117/12.2020941.

[21] V. Atienza-Vanacloig, G. Andreu-García, F.

López-García, J. M. Valiente-González, and V. Puig-Pons, "Vision-based discrimination of tuna individuals in grow-out cages through a fish bending model," *Comput. Electron. Agric.*, vol. 130, 2016, doi: 10.1016/j.compag.2016.10.009.

[22] F. Shafait *et al.*, "Towards automating underwater measurement of fish length: A comparison of semi-automatic and manual stereo-video measurements," *ICES J. Mar. Sci.*, vol. 74, no. 6, 2017, doi: 10.1093/icesjms/fsx007.

[23] M. Zhang *et al.*, "Research on evaluation method of stereo vision measurement system based on parameter-driven," *Optik (Stuttg).*, vol. 245, 2021, doi: 10.1016/j.ijleo.2021.167737.

[24] M. Hao, H. Yu, and D. Li, "The measurement of fish size by machine vision - A review," in *IFIP Advances in Information and Communication Technology*, 2016. doi: 10.1007/978-3-319-48354-2_2.

[25] V. Leemans, B. Dumont, and M. F. Destain, "Assessment of plant leaf area measurement by using stereo-vision," in *2013 International Conference on 3D Imaging, IC3D 2013 - Proceedings*, 2013. doi: 10.1109/IC3D.2013.6732085.

[26] Y. Song, C. A. Glasbey, G. Polder, and G. W. A. M. van der Heijden, "Non-destructive automatic leaf area measurements by combining stereo and time-of-flight images," *IET Comput. Vis.*, vol. 8, no. 5, 2014, doi: 10.1049/iet-cvi.2013.0056.

[27] N. Bandi, R. B. Tunyogi, Z. Szabo, E. Farkas, and C. Sulyok, "Image-Based Volume Estimation Using Stereo Vision," in *SISY 2020 - IEEE 18th International Symposium on Intelligent Systems and Informatics, Proceedings*, 2020, pp. 55–60. doi: 10.1109/SISY50555.2020.9217089.

[28] Y. Zhang *et al.*, "Accurate profile measurement method for industrial stereo-vision systems," *Sens. Rev.*, vol. 40, no. 4, pp. 445–453, 2020, doi: 10.1108/SR-04-2019-0104.

[29] H. Kieu, T. Pan, Z. Wang, M. Le, H. Nguyen, and M. Vo, "Accurate 3D shape measurement of multiple separate objects with stereo vision," *Meas. Sci. Technol.*, vol. 25, no. 3, 2014, doi: 10.1088/0957-0233/25/3/035401.

[30] J. Rantung, F. P. Sappu, and Y. Tondok, "Real-time Measurement Method for Fish Surface Area and Volume Based on Stereo Vision," *Adv. Sci. Technol. Eng. Syst. J.*, vol. 6, no. 5, pp. 141–148, 2021, doi: 10.25046/aj060516.