Food and Agriculture Organization of the United Nations

Indian Ocean Tuna Commission
Commission des Thons de l'Ocean Indien
iotc ctoi

IOTC-2026- WPDCS22-25

MatsyaMetri: An Augmented Reality-based Mobile Application for Length-Frequency Sampling of IOTC Tuna and Tuna-like Species

Eldho Varghese[1*], Thejus T. V.[1], Jayasankar Jayaraman[1], Somy Kuriakose[1], Mini K.G.[1], Grinson George[1], Muktha M.[1], Merlin J. Mariya[1], Ansuman Das[2], Sreenath K.R.[2], Sanjay Pandey[3], Mohammed Koya[3] and Surabhi Rai[3]

[1]ICAR-Central Marine Fisheries Research Institute, Kochi
[2]Fishery Survey of India, Mumbai,
[3]Department of Fisheries, Govt of India, New Delhi
*Email: eldho.varghese@icar.org.in; eldhoiasri@gmail.com

Purpose, expectation and action intended

Discussions (for information and open discussion)

The paper is to inform meeting members about the development and functionality of MatsyaMetri, an augmented reality (AR)-based mobile application designed for digital length and width measurement of tuna and tuna-like species and automated generation of length-frequency data, as presented in Sections 2–6. The paper also presents the results of a pilot validation involving yellowfin tuna specimens and discusses the potential application of the tool in fisheries-dependent data collection and monitoring programmes, as presented in Sections 7–9.

Feedback (to collect input and suggestions)

The paper is to request technical feedback and suggestions from meeting members on the measurement methodology, validation approach, data-management workflow and potential applicability of MatsyaMetri in IOTC tuna and tuna-like species sampling programmes, particularly with regard to improving the accuracy, consistency and operational suitability of length-frequency data collection, as discussed in Sections 7–9 and 11.

Conclusion (to record a concluded position or summary)

The paper is to present the preliminary findings that MatsyaMetri offers a feasible smartphone-based approach for fish biometric measurement and length-frequency data generation. The pilot validation demonstrated close agreement with conventional ichthyometer measurements, with the observed 95% limits of agreement falling within the predefined ±1 cm measurement-error limit. The findings support the potential of the application as a supplementary digital tool for fisheries monitoring, while recognising the need for further multi-species and field-based validation, as presented in Sections 7, 8 and 11.

Recommendation (to ask the meeting to endorse a recommendation)

Not applicable.

Decisions (to request formal approval of actions)

Not applicable.

Abstract

Reliable size-composition data are essential for tuna stock assessment and are routinely collected through port-sampling programmes, onboard observer activities and other fishery-dependent monitoring systems across the Indian Ocean. As tuna fisheries continue to expand and the demand for timely biological information increases, conventional measuring-board methods can become labour-intensive and limit sampling throughput during periods of high landings. *MatsyaMetri* was developed as a smartphone-based digital platform to streamline the collection of length data from tuna and tuna-like species encountered in commercial fisheries. Using the embedded camera and augmented-reality capabilities of modern mobile devices, the application estimates fish length and width from operator-selected anatomical endpoints, thereby reducing manual transcription and integrating measurements directly into a structured sampling workflow. The application supports rapid sequential measurement of multiple specimens, automatically generates length-frequency summaries and exports the resulting data for downstream analysis. In a pilot validation involving 20 yellowfin tuna specimens, *MatsyaMetri* showed close agreement with ichthyometer measurements. The resulting 95% limits of agreement for both length and width were within the predefined permissible measurement-error limits. At a 10-cm class interval, the application and manually derived length-frequency distributions assigned all 20 specimens to the same size classes. These results support the feasibility of *MatsyaMetri* as a practical field-oriented tool for fisheries monitoring. However, larger and more diverse field validations are required to assess its performance across species, body sizes, operating environments, and field conditions.

Keywords: Tuna fisheries, length sampling, size-frequency distribution, digital data collection, augmented reality, mobile technology, stock assessment, observer programmes, fisheries monitoring, *MatsyaMetri*

1. Introduction

Fish length and body width measurements are among the most commonly collected biological measurements in fisheries science, aquaculture and marine biological monitoring. In tuna fisheries, accurate information on fish size is important for stock assessment because length composition data provide valuable information on the size and age structure of the exploited populations. These data contribute to the estimation of growth, fishery selectivity and biomass and help assess changes in stock status and the effects of fishing pressure [1]. The reliability of these assessments therefore depends directly on the accuracy and consistency with which the underlying measurements are taken.

Conventional fish measurement relies on tools such as ichthyometers, measuring boards, rulers and callipers. These methods are labour-intensive and time-consuming particularly when large numbers of specimens have to be assessed within a short period as they require individual positioning and measurement of each fish specimen manually. Moreover, manual transfer of measurements to spreadsheets or analytical software introduces additional processing steps and increases the risk of recording and transcription errors, especially at busy landing centres and survey locations.

To overcome some of these challenges, digital imaging and computer-vision techniques have increasingly been investigated for automated fish size measurement. Earlier studies demonstrated that fish orientation and body length could be derived from digital images [2,3], while stereo-camera systems enabled three-dimensional estimation of fish dimensions [4–6]. However, such systems may require controlled imaging environments, reference objects, multiple cameras or relatively complex computational procedures, potentially limiting their application under routine field conditions. Recent advances in deep learning have further improved automated fish measurement by enabling the detection of fish and identification of anatomical landmarks, including the head and tail, from images [7–14]. Despite their advantages, these approaches may be influenced by factors such as overlapping specimens, curved bodies, variation in fish orientation, illumination and background complexity. These challenges emphasise the need for measurement solutions that are practical in field environments while maintaining reliable specimen-level records.

Along with these developments, mobile augmented reality (AR) has emerged as an approach for contactless measurement. Devices equipped with cameras and inertial sensors can use AR frameworks such as Google ARCore to track device movement and establish spatial information about the surrounding environment [15]. After identifying a suitable supporting surface, points selected by the user can be converted into positions in physical space through AR hit-testing. This capability makes it possible to estimate real-world distances using a single smartphone without requiring a separate physical scale for each measurement. Previous research has also demonstrated the feasibility of ARCore-based approaches for fish-length estimation [8].

However, a workflow suited to fisheries data collection should go beyond accurate measurements by linking each measurement to the corresponding fish, organize the data by sampling session, store it securely and make it available for downstream analysis. Automated generation of length-frequency data can further reduce the amount of post-processing workload on researchers and field enumerators.

In this study, we present *MatsyaMetri*, an Android-based AR application developed for contactless measurement of fish length and width using a standard smartphone. The application uses ARCore to identify a horizontal supporting surface and establish a metric spatial reference. The user identifies the required anatomical endpoints through the camera interface, after which ARCore hit-testing determines their corresponding positions on the detected plane. The distance between these points is subsequently calculated and expressed in centimetres. The system is designed around operator-selected anatomical landmarks and does not rely on automated fish segmentation or three-dimensional reconstruction of the specimen.

Beyond measurement, *MatsyaMetri* incorporates a field-oriented data-management workflow. Measurements can be grouped into sampling sessions, associated with specimen information, stored locally and exported as comma-separated values (CSV) files for further analysis. The application also includes a length-frequency analysis module that groups observations according to user-defined class intervals and produces frequency and cumulative-frequency summaries. Authentication and cloud synchronisation are

supported through a backend system, while the principal measurement and recording functions can operate without continuous internet connectivity, making the application suitable for field situations where network access may be limited.

2. System Overview

MatsyaMetri is a native Android application developed using Kotlin and Jetpack Compose, following the Model–View–ViewModel (MVVM) architecture. A Node.js and PostgreSQL server supports authentication and cloud synchronisation, while measurements are stored locally using Room (SQLite) for offline-first field use and synchronised when connectivity is available. Passwordless authentication uses email-based one-time passwords (OTPs), with JSON Web Tokens (JWTs) for secure session management [16]. OTPs are cryptographically generated, bcrypt-hashed, time-limited, and single-use. Following successful verification, an HS256-signed JWT [16] is issued and securely stored on the device using EncryptedSharedPreferences. No passwords are stored.

3. Measurement Principle

MatsyaMetri measures length and width using ARCore horizontal-plane detection and hit-testing. The fish is laid roughly flat on a surface such as a measuring tray, lab table or boat deck. The app detects this surface as a horizontal plane. The operator then picks two anatomical endpoints on the camera view. For length, these are the tip of the snout and the rear end of the caudal fin. For width, they mark the widest part of the body. The app does not model the surface of the fish. Instead, each tap is projected onto the detected plane, and the Euclidean distance between the two points is worked out in centimetres. This assumes the fish lies flat enough and that the endpoints can be picked accurately. For every tap, ARCore runs a hit test and keeps only points that fall on a tracked plane. Anchors are fixed at these points, and the result appears on the camera view as a line with its value.

4. Data Management and Session Structure

Measurements are organised into sessions, typically corresponding to a single landing-centre visit or sampling occasion. Each session stores the image reference, length and width in centimetres and species information. On Android 10 and later, photos are saved to the gallery through MediaStore. On older versions, they are written directly to storage and a media scan is triggered. Either way, the images can be opened outside the app for checking or reprocessing. The session screen of the application is shown in Figure 1.

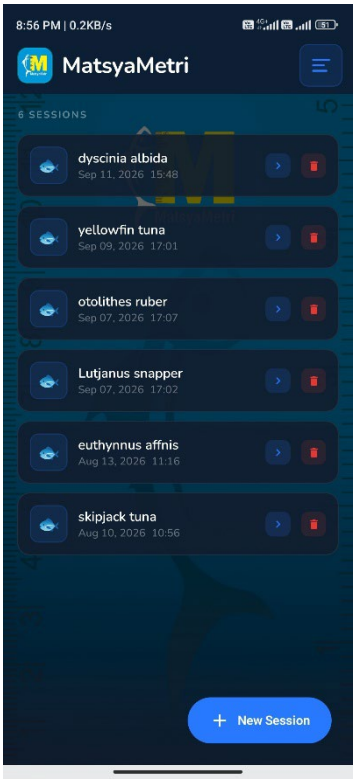

Fig. 1 *MatsyaMetri* app Session Screen

5. Length-Frequency Analysis Module

The length-frequency analysis module is a principal scientific component of the application and becomes available once a session contains two or more measurements. When the module is invoked, the investigator specifies a class-interval width. The default interval is 5 cm, but the interval can be adjusted by the user according to the size range and precision required for the target species. The application automatically groups the recorded measurements into the specified length classes and generates frequency and cumulative-frequency summaries. The workflow implemented in the length-frequency analysis module is illustrated in Figure 2.

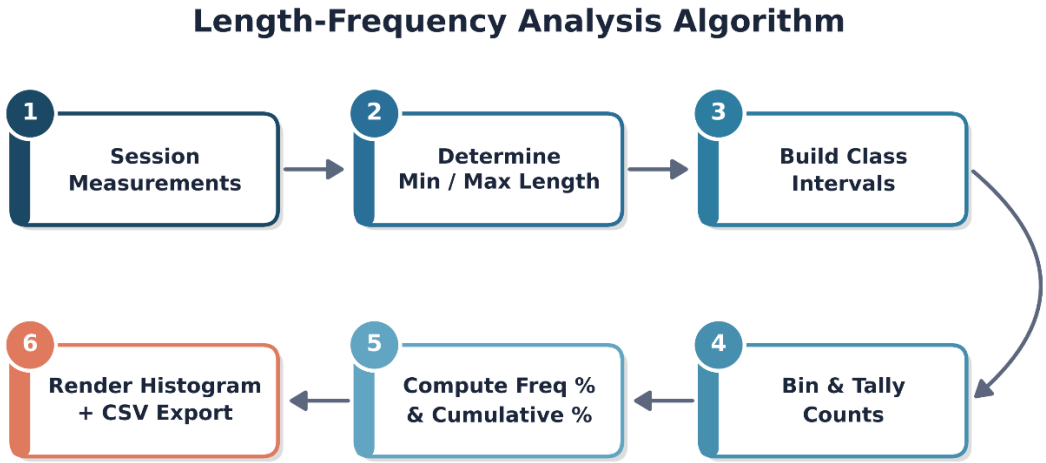

Fig. 2 Workflow of the length-frequency analysis algorithm implemented in *MatsyaMetri*

6. How to Use *MatsyaMetri*

The following workflow describes the basic procedure for registering, measuring fish, analysing the resulting data, and exporting the measurements. A quick workflow is given in Figure 3.

Step 1: Register Your Account

Create your *MatsyaMetri* account in just a few steps.

1. Enter your email ID and complete the registration.
2. Check your email for the OTP (One-Time Password).
3. Enter the OTP to verify your account.

Step 2: Log In

Use your registered credentials to log in and access the *MatsyaMetri* dashboard.

Step 3: Create a New Session

Organise your measurements by creating a session for each species or sampling event.

1. Tap "+ New Session" on the home screen.
2. Enter a suitable session name- for example, the fish species or date of catch.
3. Measure multiple individuals of the same species within the same session.
4. Once sampling is complete, create a new session for the next species or sampling event.

Step 4: Set Up for Measurement

Get your phone ready for accurate AR-based measurement.

1. Point the camera towards a flat surface.
2. Slowly move the phone across the surface.
3. ARCore will begin mapping the surface, and white feature points will appear.
4. Continue moving the phone until enough feature points are detected.

Step 5: Measure Fish Length and Width

Now measure the fish using the AR crosshair.

To measure length:

1. Aim the crosshair at one end of the fish.
2. Tap "+" to mark the first point.
3. Move the crosshair to the other end of the fish.
4. Tap "+" again.
5. The blue line displays the measured fish length.

To measure width:

1. Wait until the crosshair turns green.
2. Tap one side of the fish.

3. Move to the opposite side and tap again.
4. The green line displays the measured fish width.

Step 6: Save the Measurement

Once the measurement is complete:

1. A dialog box will display the length and width.
2. Review the measurements.
3. Tap "Save".
4. The measurement and photograph are saved to your phone gallery and to the current *MatsyaMetri* session.

Step 7: Generate Length–Frequency Data

MatsyaMetri automatically organises your measurements for length-frequency analysis.

1. Tap the menu icon on the AR measurement screen.
2. Open the Summary Table to review your measurements.
3. Tap "Length Frequency Analysis".
4. Provide appropriate bin size in the dialog box that appears
5. *MatsyaMetri* automatically compiles the measurements and generates the length-frequency distribution with the given bin size.

Step 8: Export Your Data

Take your measurements and analysis with you for further use.

1. Tap the Download icon.
2. Export your measurements and Length-frequency Analysis as a CSV file.
3. Use the exported file for further analysis, reporting or data management.



Fig. 3 Quick workflow for using the *MatsyaMetri* application

7. Validation

A pilot validation was carried out at the ICAR-Central Marine Fisheries Research Institute (CMFRI). Length and width of twenty individual specimens of yellowfin tuna (*Thunnus albacares*) were measured using both methods. This sample size was selected as a feasibility pilot to validate the measurement pipeline and length-frequency analysis workflow end-to-end before undertaking a larger, multi-species validation campaign. Accordingly, the results are interpreted as evidence of feasibility rather than as a comprehensive validation of the application across species and field environments. The equipment and conditions used for the laboratory validation are presented in Table 1.

Table 1. Equipment and conditions used in the laboratory validation study

Item	Specification
Reference instrument	Standard wooden/fibreglass ichthyometer
Test device	Redmi Note 9 Pro Max Android smartphone
Application version	*MatsyaMetri* v1.0
Lighting conditions	Indoor laboratory conditions under tube-light illumination

A trained investigator measured the fish length and width using a standard ichthyometer, with measurements recorded to the nearest 0.1 cm, while the second investigator used *MatsyaMetri* app under normal lighting and handling conditions for measuring the same (Figure 4). The measurements were conducted independently to minimise potential observer bias. An acceptable limit of agreement of ±1 cm was specified for both length and width measurements, based on the conventional 1-cm measurement resolution used in fisheries sampling [17]. An error within this limit would therefore be unlikely to displace a specimen by more than one adjacent size class. Following Giavarina [18], agreement was considered acceptable when both the 95% limits of agreement and their corresponding 95% confidence intervals remained within the predefined ±1 cm acceptance range.

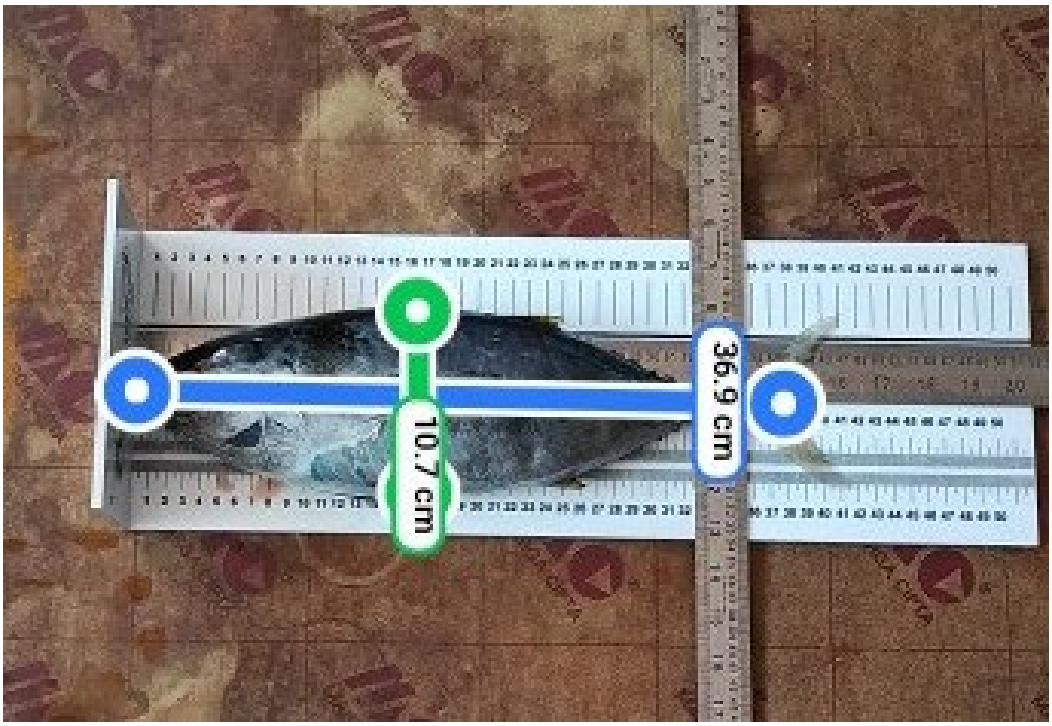

Fig. 4 App generated length and width image

7.1 Bland-Altman Analysis

Bland–Altman analysis is used to assess agreement between two quantitative measurement methods by examining the differences between paired measurements [19]. Agreement is evaluated by estimating the mean difference (bias) and the 95% limits of agreement (LoA). The mean difference provides an estimate of the systematic difference between the two methods, while the LoA indicate the range within which approximately 95% of the differences between paired measurements are expected to lie.

Let x_i and y_i be the ith observations measured using method A and method B respectively. Then, paired difference is defined as,

$$d_i = x_i - y_{i.}$$

The mean difference ($\bar{d}$), 95% LoA and their corresponding confidence intervals were calculated using the following equations

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i\,, \tag{1}$$

$$95\%\ \text{LoA} = \bar{d} \pm 1.96 \times \text{SD}(d), \tag{2}$$

where $\text{SD}(d)$ is the standard deviation of paired differences and n is the number of paired observations.

To quantify the precision and uncertainty associated with these estimates, confidence intervals (CIs) were calculated for both the estimated difference ($\bar{d}$) and the limits of agreement (LoA) using the following equations.

$100(1-\alpha)\%$CI of bias

$$\bar{d} \pm t_{(1-\alpha/2,\ n-1)} \times \text{SE}(\bar{d}), \tag{3}$$

$100(1-\alpha)\%$CI of Lower LoA

$$\left[\bar{d} - 1.96 \times \text{SD}(d)\right] \pm t_{(1-\alpha/2,\ n-1)} \times \text{SE}(\text{Lower LoA}), \tag{4}$$

$100(1-\alpha)\%$CI of Upper LoA

$$\left[\bar{d} + 1.96 \times \text{SD}(d)\right] \pm t_{(1-\alpha/2,\ n-1)} \times \text{SE}(\text{Upper LoA}), \tag{5}$$

where

$$\text{SE}(\bar{d}) = \frac{\text{SD}(d)}{\sqrt{n}}, \tag{6}$$

$$\text{SE}(\text{LoA}) = \text{SD}(d)\sqrt{\frac{1}{n} + \frac{(1.96)^2}{2(n-1)}}\,, \tag{7}$$

$t_{(1-\alpha/2,\ n-1)}$ is the critical value of the t-distribution with $n-1$ degrees of freedom and at α level of significance.

7.2 Assessment of Measurement Accuracy and Agreement

The results of the Bland–Altman analysis of the pilot validation are summarised in Table 2. The assumptions underlying the Bland–Altman analysis were assessed by examining the distribution of the paired differences, potential outlying observations and proportional bias. There was no significant evidence of proportional bias or departure from normality was observed in the distribution of the measurement differences.

Table 2. Comparison of the two methods of measurements

Dimension	MAE	RMSE	Bias (95% CI)	Lower LoA (95% CI)	Upper LoA (95% CI)
Length (cm)	0.245	0.297	-0.005 (-0.148, 0.138)	-0.603 (-0.851, -0.355)	0.593 (0.345, 0.841)
Width (cm)	0.190	0.202	+0.110 (0.028, 0.192)	-0.232 (-0.373, -0.090)	0.452 (0.310, 0.593)

Note. All values are expressed in centimetres; MAE = mean absolute error; RMSE = root mean square error; LoA (limits of agreement) = (bias ± 1.96×SD of differences); 95% CI of bias = bias ± $t_{0.975,19} \times \mathrm{S.E(bias)}$. 95% CI of upper LoA = upper LoA ± $t_{0.975,19} \times \mathrm{S.E(upper\ LoA)}$. 95% CI of lower LoA = lower LoA ± $t_{0.975,19} \times \mathrm{S.E(lower\ LoA)}$.

For length measurement, *MatsyaMetri* showed a negligible bias of −0.005 cm, indicating minimal systematic difference from the manual measurements. The 95% limits of agreement ranged from −0.603 to 0.593 cm, indicating that the observed differences between *MatsyaMetri* and ichthyometer length measurements were within the predefined permissible limit of ±1 cm. The relatively small MAE (0.245 cm) and RMSE (0.297 cm) further indicate limited measurement error. Figure 5 demonstrates the close agreement between the two measurement methods.

For width measurement, the application exhibited a small positive bias of 0.110 cm, indicating a tendency to slightly overestimate the manual measurements. The 95% CI for the mean bias (0.028 to 0.192 cm) did not include zero, indicating evidence of a statistically significant positive bias. However, the magnitude of the bias was small (0.11 cm), indicating that *MatsyaMetri* width measurements were only slightly higher than the corresponding ichthyometer measurements. The 95% limits of agreement (−0.232 to 0.452 cm) were within the predefined permissible measurement-error limits, indicating close agreement between the two methods. The lower MAE (0.190 cm) and RMSE (0.202 cm) for width also indicate close agreement between the app-based and manual measurements. Figure 6 provides the summary of Bland-Altman analysis for length and width measurements.

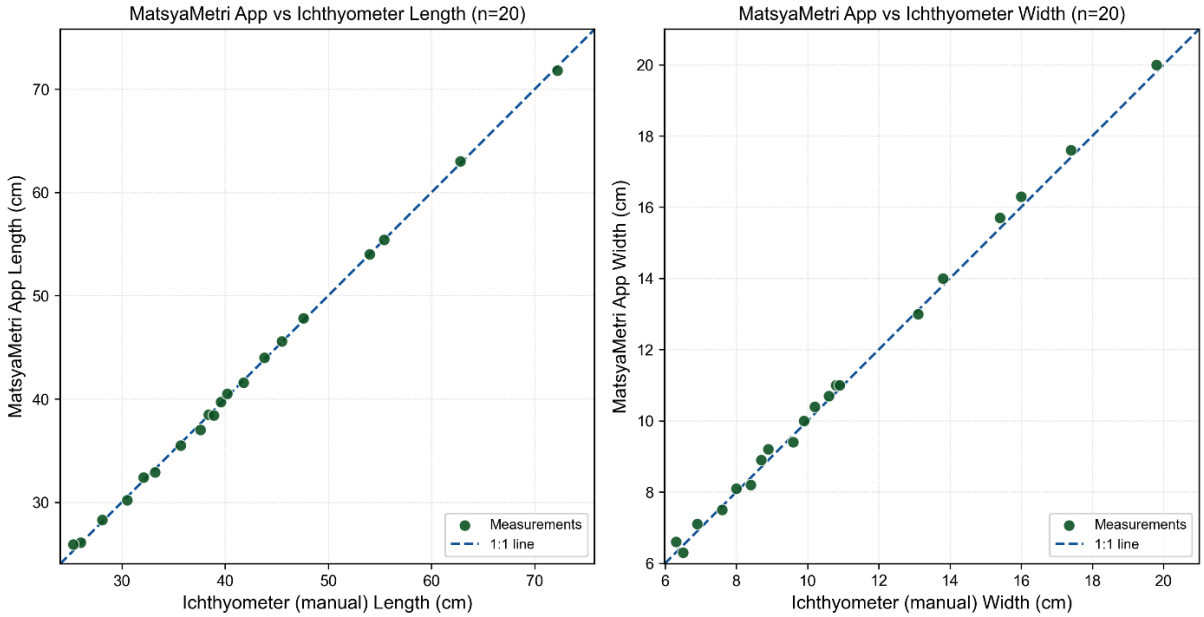

Fig. 5 Comparison of *MatsyaMetri* app and ichthyometer measurements of length and width against the 1:1 line

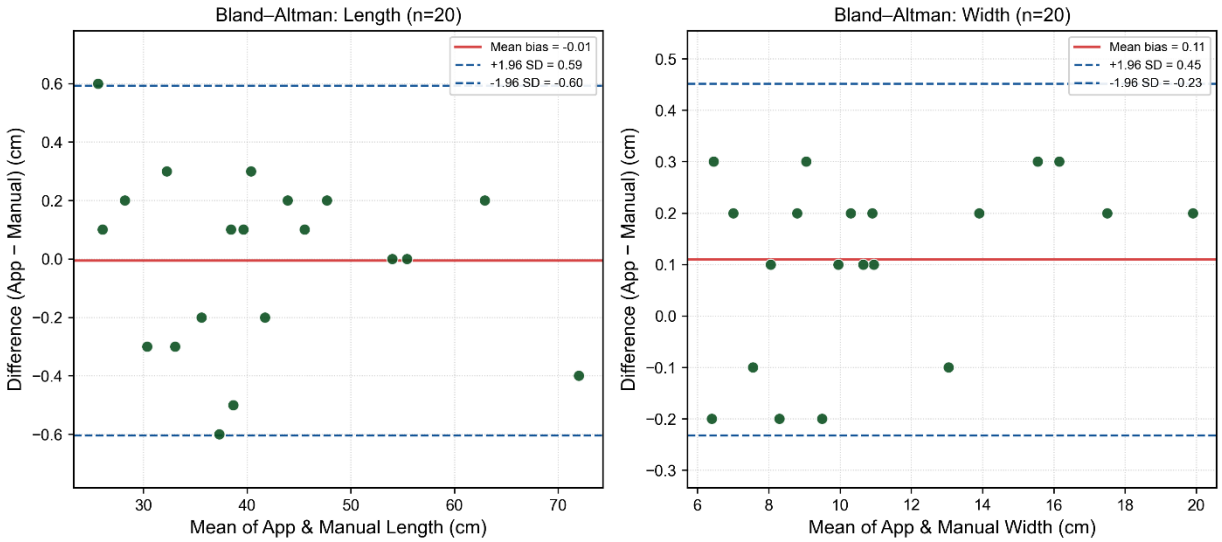

Fig. 6 Bland-Altman analysis

7.3 Length-Frequency Distribution

The length-frequency distribution produced automatically by the *MatsyaMetri* application was compared with the corresponding distribution obtained from manual ichthyometer measurements of the same 20 specimens. The two approaches yielded identical frequencies across the six length classes between 20 and 80 cm (3, 8, 5, 2, 1 and 1 specimens respectively), indicating that the two methods produced consistent classification of all specimens into the same length categories.



Fig. 7(a) Length-frequency distributions generated from *MatsyaMetri*

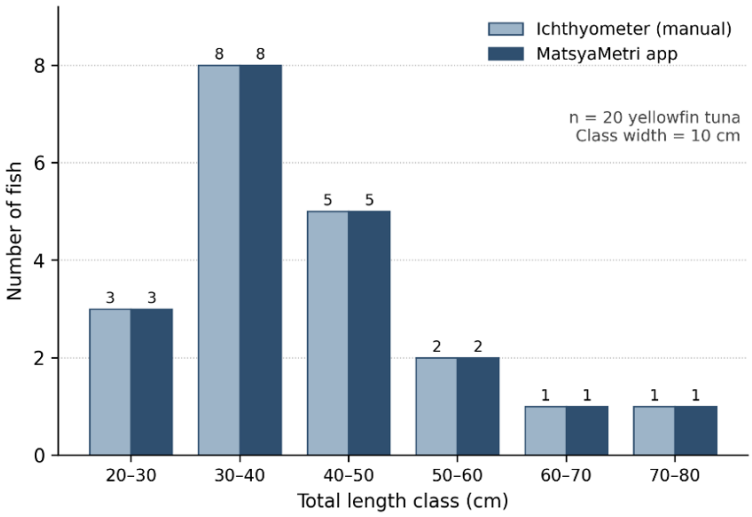

Fig. 7(b) Comparison of length-frequency distribution generated from *MatsyaMetri* and manually constructed length frequency distribution based on ichthyometer measurements

8. Limitations

The proposed measurement methodology relies on the detection of a supporting plane and the three-dimensional coordinates obtained through ARCore hit-testing. Consequently, measurement accuracy may be affected under challenging imaging conditions, including insufficient lighting, poor visual contrast, reflective surfaces or improper alignment of the specimen with the measurement plane. These factors may influence the precise placement of measurement points, particularly when anatomical endpoints are poorly defined. The current implementation does not incorporate the ARCore Depth API or computer-vision-based segmentation of fish specimens. These capabilities could potentially enhance the measurement process and therefore constitute possible areas for future development, but they are not part of the system evaluated in the present study.

9. Implications for Fisheries Monitoring

The ability to generate near-real-time length-frequency data under field conditions has important implications for fisheries monitoring and management. The availability of timely measurements could support more frequent updating of growth and mortality parameter estimates and facilitate the early identification of changes in population size structure associated with recruitment patterns or variations in fishing pressure. Furthermore, the standardized measurement workflow may improve the consistency and comparability of data collected by field teams operating across geographically dispersed locations compared with conventional manual measurement procedures. By streamlining the collection and processing of length-frequency data, the application has the potential to improve the efficiency of field-based sampling and provide more timely datasets for subsequent use in fisheries assessment and management workflows.

10. Software Availability

MatsyaMetri is freely available for Android devices via the Google Play Store: https://play.google.com/store/apps/details?id=com.arrulermeasure. The application requires an ARCore-compatible Android devices.

11. Conclusion and Future Work

MatsyaMetri is a smartphone based augmented-reality application designed to enable contactless fish biometric measurement while facilitating the processing of length-frequency data in a single workflow. The integration of measurement, data recording, length-class assignment and frequency analysis into a single Android-based workflow reduces the need for separate manual measurement and data-processing steps, thereby offering a more efficient alternative to conventional approaches.

Future development of *MatsyaMetri* will aim to extend its functionality into a more comprehensive fisheries data-collection platform. Planned enhancements include the incorporation of species-specific length–weight relationships for weight estimation [20], biomass-frequency analysis and improved measurement of curved or non-planar specimens through the integration of depth information or image-segmentation techniques. Further validation across multiple sites, species, and field conditions will also be undertaken to evaluate the robustness and broader applicability of the system.

Acknowledgements

The authors sincerely thank the ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi, for providing the necessary facilities and institutional support to carry out this research. The study was supported by the Indian Council of Agricultural Research (ICAR), Department of Agricultural Research and Education, Government of India, through the ICAR-National Fellow Project (F.No. Agril.Edn./27-11/NF/2025/HRD). We are especially indebted to the field observers of CMFRI deployed along the Indian coast for their invaluable assistance in testing and validating the application. The authors also extend their gratitude to the Indian Ocean Tuna Commission (IOTC) for the opportunity to present this paper at the 22nd Working Party on Data Collection and Statistics (WPDCS22).

References

[1] Urtizberea, A., Correa, G. M., Langley, A., Merino, G., Fu, D., Chassot, E., and Adam, S. (2024). Stock assessment of yellowfin tuna in the Indian Ocean for 2024. IOTC-2024-WPTT26-11. Indian Ocean Tuna Commission (IOTC), Working Party on Tropical Tunas, 26th Session, 1-149.

[2] Strachan, N. J. C., Nesvadba, P., and Allen, A. R. (2006). Automated measurement of species and length of fish by computer vision. *Fisheries Research*, 80(2–3), 203–208.DOI: 10.1016/j.fishres.2006.04.009

[3] Andrialovanirina, N., Ponton, D., Behivoke, F., Mahafina, J., and Léopold, M. (2020). A powerful method for measuring fish size of small-scale fishery catches using ImageJ. *Fisheries Research*, 223, 105425.

[4] Letessier, T. B., Juhel, J.-B., Vigliola, L., and Meeuwig, J. J. (2015). Low-cost small action cameras in stereo generate accurate underwater measurements of fish. *Journal of Experimental Marine Biology and Ecology*, 466, 120–126.

[5] Ubina, N. A., Cheng, S.-C., Chang, C.-C., Cai, S.-Y., Lan, H.-Y., and Lu, H.-Y. (2022). Intelligent underwater stereo camera design for fish metric estimation using reliable object matching. *IEEE Access*, 10, 74605–74619.

[6] Zhou, M., Shen, P., Zhu, H., and Shen, Y. (2023). In-water fish body-length measurement system based on stereo vision. *Sensors, 23*, 6325.

[7] Alvarez-Ellacuria, A., Palmer, M., Catalan, I. A., and Lisani, J. L. (2020). Image-based, unsupervised estimation of fish size from commercial landings using deep learning. *ICES Journal of Marine Science, 77*(4), 1330–1339.

[8] Kang, S.-B., Kim, S.-G., Lee, S.-H., and Im, T.-H. (2024). A study on the automation of fish species recognition and body length measurement system. *Fishes*, 9(9), 349.

[9] Monkman, G. G., Hyder, K., Kaiser, M. J., and Vidal, F. P. (2019). Using machine vision to estimate fish length from images using regional convolutional neural networks. *Methods in Ecology and Evolution, 10*(12), 2045–2056

[10] Palmer, M., Álvarez-Ellacuría, A., Moltó, V., and Catalán, I. A. (2022). Automatic, operational, high-resolution monitoring of fish length and catch numbers from landings using deep learning. *Fisheries Research, 246*, 106166.

[11] Petrellis, N. (2021). Measurement of fish morphological features through image processing and deep learning techniques. *Applied Sciences, 11*(10), 4416.

[12] Saleh, A., Jones, D., Jerry, D., and Azghadi, M. R. (2023). MFLD-net: A lightweight deep learning network for fish morphometry using landmark detection. *Aquatic Ecology*, 57, 913–931.

[13] Tonachella, N., Martini, A., Martinoli, M., Pulcini, D., Romano, A., and Capoccioni, F. (2022). An affordable and easy-to-use tool for automatic fish length and weight estimation in mariculture. *Scientific Reports, 12*, 15642.

[14] Tseng, C. H., Hsieh, C. L., and Kuo, Y. F. (2020). Automatic measurement of the body length of harvested fish using convolutional neural networks. *Biosystems Engineering*, *189*, 36-47.

[15] Google. (2024). *ARCore overview*. Google Developers. https://developers.google.com/ar/discover

[16] Jones, M., Bradley, J., and Sakimura, N. (2015). *Json web token (jwt)* (No. rfc7519).

[17] Holden, M. J., and Raitt, D. F. S. (1974). *Manual of fisheries science. Part 2: Methods of resource investigation and their application*. FAO Fisheries Technical Paper No. 115. Rome: Food and Agriculture Organization of the United Nations. 255 p.

[18] Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochemia Medica*, 25(2), 141–151.

[19] Bland, J. M., and Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet*, 327(8476), 307–310.

[20] De Robertis, A., and Williams, K. (2008). Weight–length relationships in fisheries studies: The standard allometric model should be applied with caution. *Transactions of the American Fisheries Society*, 137(3), 707–719.