

Modification of Hand Lines with Electric Motors and Monitor Control System as an Alternative to Manual Labor in Small-Scale Fisheries

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ABSTRACT

Labor shortages and high physical workload remain major challenges in small-scale tuna handline fisheries due to dependence on manual hauling. This study evaluates a modified handline system that integrates a 12 VDC electric motor, winch, and IoT-based monitoring control as an alternative technology. Field experiments conducted in Mentawai waters, West Sumatra, Indonesia, showed that the proposed system significantly reduced the hauling time from 976 ± 188 s to 610 ± 7 s and increased the hauling speed by about 60% (0.15 to 0.24 m/s). In addition, labor requirements decreased from six to two crew members (66.7% efficiency), while system performance remained stable and unaffected by operator fatigue. These findings demonstrate that electrified handline systems can improve operational efficiency, reduce physical workload, and provide a practical technological solution to labor limitations in small-scale tuna fisheries. Further studies with larger datasets are recommended to confirm these results.

Keywords-tuna fisheries; electric handline; IoT monitoring; labor efficiency; fishing technology innovation

I. INTRODUCTION

Tuna fishing is an economically important fishing sector in Indonesia and a major contributor to global tuna production, accounting for approximately 19.1% of total supply [1]. Handline fishing is widely used by small-scale fishers to catch yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), and skipjack (*Katsuwonus pelamis*) due to its effectiveness for large pelagic species [2-4]. However, most handline operations remain manual, particularly during the hauling process, which requires substantial physical effort.

Manual hauling presents significant physical risks to fishers, including muscle fatigue, repetitive strain injuries, reduced coordination, and a higher likelihood of accidents during the pulling process [5-6]. Prolonged exertion can also compromise safety and operational efficiency, making mechanized systems an important technological solution. Labor shortages and limited crew availability further reduce operational efficiency in small-scale tuna fisheries. To address this issue, several studies have introduced electric or mechanized hauling systems to reduce physical workload and improve efficiency [7]. However, these studies mainly focused on mechanical performance and have not evaluated the integration of electric hauling systems with IoT-based control and monitoring technology under actual fishing conditions. This represents a research gap in the practical application of integrated electric and digital handline systems.

This research project developed a modified tuna handline integrating an electric winch and an IoT-based control and monitoring system. The novelty of this work lies in its technological integration and field-based evaluation focusing on hauling speed, operational efficiency, and manpower reduction in small-scale tuna fisheries in West Sumatra. The aim of this study was to evaluate the effectiveness of the proposed handline in improving operational efficiency, reducing labor workload, and supporting sustainable tuna fishing activities in West Sumatra.

II. METHOD

A. Time and Location

This research was conducted in the Mentawai waters of West Sumatra, a potential tuna fishing ground in the Indian Ocean. The location was selected based on oceanographic conditions supporting tuna presence, making it suitable for testing both manual and modified handlines. Field activities were conducted from 20 May to 05 June 2025, including preparation, fishing trials, and onboard observations to capture operational and environmental variations. The fishing trials were conducted using a small-scale wooden fishing vessel commonly operated by local fishers in the study area, representing typical handline fishing operations in West Sumatra.

During the trials, sea conditions were generally moderate, characterized by ocean wave motion and relatively stable weather conditions. In some instances, higher wave conditions were observed during rainfall periods. These conditions reflect the typical operational environment for small-scale tuna fishing activities.

B. Materials and Tools

This research used conventional and modified handlines as the main objects during tuna fishing trials. The conventional handline served as a performance baseline, while the modified handline integrated a 12 VDC motor, winch, and gear reducer to increase hauling torque, reduce physical workload, and accelerate line retrieval. A control module was also included to ensure controlled operation without changing the basic handline fishing principles. Figure 1 shows the modified handline used in this study.

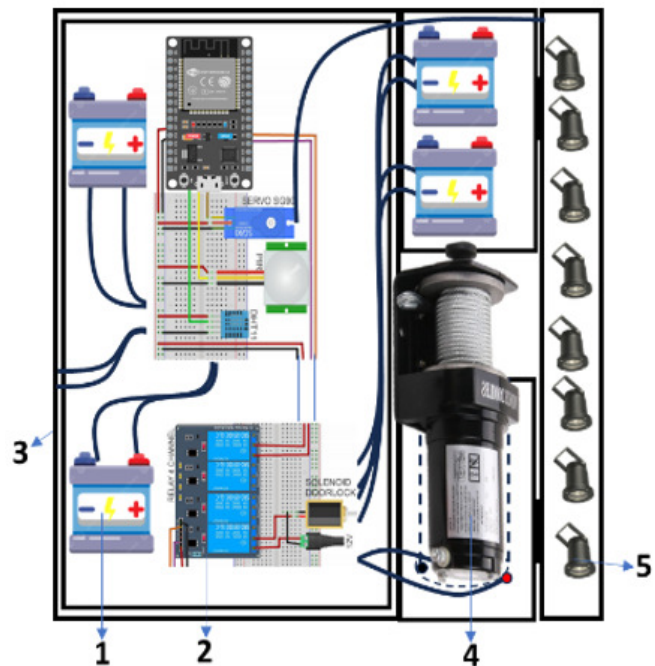


Fig. 1. Modified handline.

TABLE I. MATERIALS AND TOOLS OF THE MODIFIED HANDLINE

No	Material/Tool	Specification	Function
1	12 V Battery	12 V VRLA sealed lead-acid battery, capacity 40–70 Ah.	Main electrical power supply
2	DC Relay	Electromagnetic DC relay, 12 V DC, 30–40 A, 14 V DC, heat-resistant plastic housing.	Motor current control and protection
3	IoT Device	ESP32, dual-core 240 MHz, Wi-Fi and Bluetooth, 3.3 V.	IoT system control and data communication unit
4	DC Winch 12V	12 V electric winch, DC motor 300–500 W, current 20–40 A, reduction gearbox $\pm 1:30$, pulling capacity 30–80 kg, hauling speed 0.5–1.0 m/s.	Line pulling and winding mechanism
5	DC LED Lamp	12 V DC LED lamp, power 1–3 W, current 20–100 mA, two-wire system (+/-)	Light source for fish attraction

C. Data Collection

Data collection was conducted through field observations and direct measurements at tuna fishing grounds in West Sumatra. The measured parameters included operational speed (m/s), hauling time (s), work efficiency (%), and labor requirements. The conventional system refers to manual handlines operated by fishermen, where typically 12 individual handlines were simultaneously operated from one vessel. In contrast, the proposed handline system was developed to improve hauling efficiency through mechanization. The comparison focused on hauling performance per unit, emphasizing hauling time, operational speed, and labor requirements rather than total catch. Both conventional and modified handlines used the same fishing line length of 150 m to ensure a fair performance comparison.

Fishing trials were conducted simultaneously at the same location from 19:00 to 06:00 with two-hour operational intervals. All activities were recorded to ensure an objective comparison between conventional and modified systems.

D. Data Analysis

Data analysis was conducted to comprehensively assess the performance of a modified handline that is designed to partially replace manpower in tuna fishing operations. The analysis covered two main aspects: technical and ergonomic.

Technically, measurements were made on the speed of the setting and hauling process (V), calculated using

$$V = \frac{L}{T} \quad (1)$$

where L is the length of the rope that is stretched or pulled (m) and T is the operating time (s). This speed value is used to assess the improvement in the mechanical performance of the gear compared to the conventional operation.

Ergonomic aspects were analyzed by measuring the reduction in human workload R , calculated as a percentage:

$$R = \frac{N_m - N_a}{N_m} \times 100\% \quad (2)$$

where E_i is labor efficiency (%), N_m is the number of workers required in the conventional handline system (persons), and N_a is the number of workers required in the modified handline system (persons).

Statistical analysis was performed using descriptive statistics presented as mean \pm standard deviation (SD). To evaluate the differences in hauling time and operational speed between conventional and modified handline systems, an independent sample t-test was applied at a 95% confidence level ($p < 0.05$). This statistical approach was used to support the performance comparison under field experimental conditions.

The results of this analysis provide an empirical basis for assessing the effectiveness of the modified handline as an efficient, ergonomic fishing technology innovation that reduces dependence on manpower in sustainable capture fisheries.

III. RESULTS AND DISCUSSION

This study compares conventional and modified electric handline systems, both operating under the same fishing principle. In the conventional system, all operations rely on manual labor, resulting in a high physical workload and requiring significant endurance and coordination, particularly when handling strong and aggressive tuna [8]. This condition can reduce efficiency and increase labor requirements. Figure 2 shows the conventional handline used by fishers.

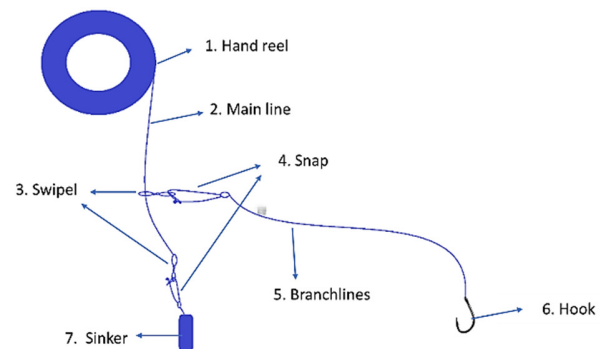


Fig. 2. The conventional handline for tuna fishing

In contrast, the modified electric handline reduces physical workload through a motorized hauling system with controllable torque and speed, resulting in faster and more consistent operations. This system also improves safety, reduces labor needs, and increases fishing effectiveness. Previous fishery studies have reported similar improvements in hauling performance and labor efficiency when using mechanized handline systems [9]. The modified system is equipped with an ESP32-based control and monitoring module, as shown in Figure 3.

The observations focused on the performance of the conventional handline system, which consisted of 12 individual handline units operated simultaneously on a single vessel. Throughout the observation period, a total of 48 tunas were successfully captured. Hauling time was systematically measured for each operation to evaluate the efficiency of the conventional system. Figure 4 illustrates the detailed results of these measurements, providing a comprehensive overview of the operational performance of the handline units.

Observations recorded 48 fish caught during the study. The conventional handline hauling time ranged from 540 s (10 kg fish) to 1,440 s (68 kg fish), with an average of 976 ± 188 seconds ($n = 48$). Larger fish required longer hauling time due to their greater strength, consistent with previous findings that hauling time depends on fish size [10].

Observations of the modified handline showed that 5 fish were caught, with hauling times ranging from 602 s (10 kg) to 620 s (37 kg), averaging 610 ± 7 s ($n = 5$), confirming improved hauling efficiency [11]. Given the limited number of observations for the modified system ($n = 5$), these findings should be interpreted as preliminary results.

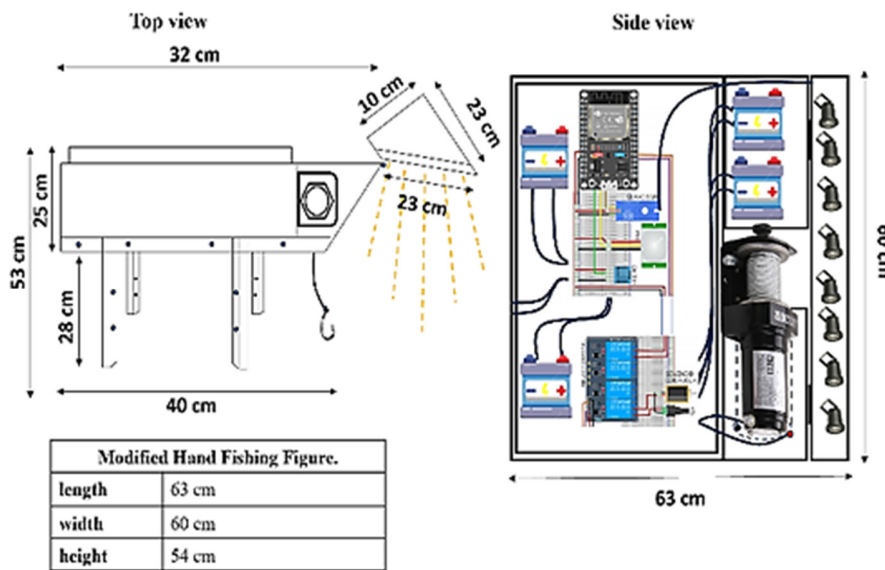


Fig. 3. Modified handline unit.

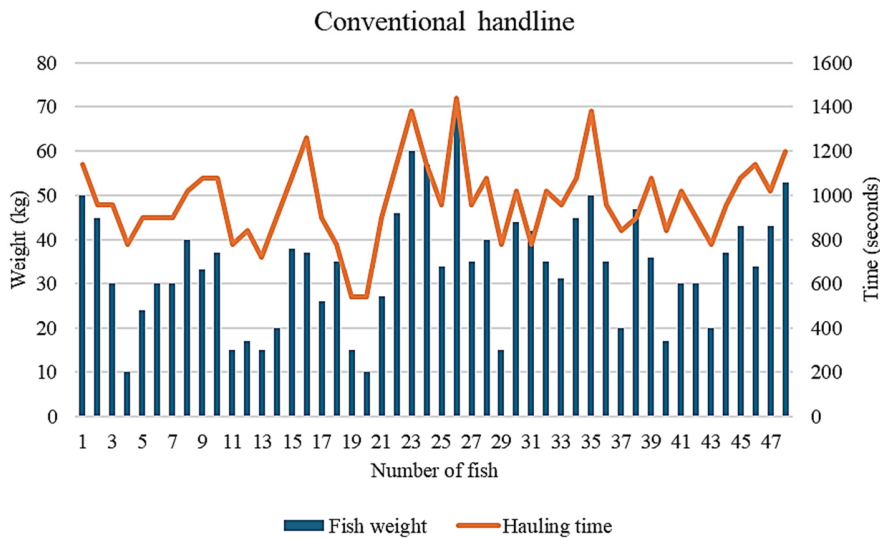


Fig. 4. Hauling time on the conventional handline fishing gear.

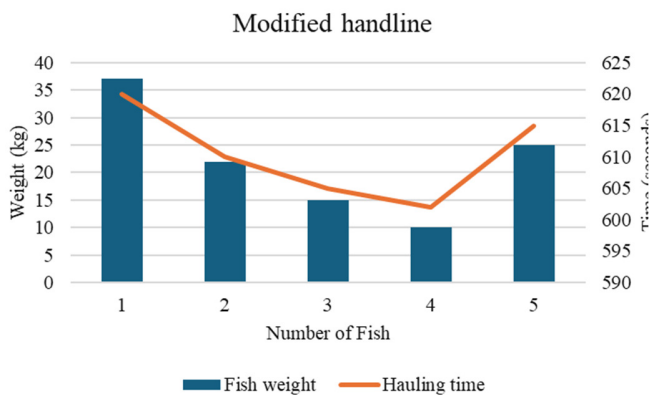


Fig. 5. Hauling time on a modified handline fishing gear.

A statistical comparison between the two systems shows that the modified handline significantly reduced hauling time compared to the conventional system. The conventional system recorded 976 ± 188 s, whereas the modified system required only 610 ± 7 s. Independent-samples t-test results confirmed that this difference was statistically significant ($p < 0.001$), which indicates that the electric hauling mechanism provides more consistent and efficient hauling performance.

The difference in hauling time is influenced by human physical limitations, particularly muscle fatigue from repetitive movements, which reduces hauling efficiency. In contrast, electric systems provide a stable and consistent force that is unaffected by fatigue. Electric motors with control systems are capable of maintaining stable speed and torque during operation [12]. In the context of fishery applications, this stability contributes to more consistent hauling performance

compared to manual systems. The modified system reduced the hauling time by about 366 s, improving fishing effectiveness.

To ensure a fair comparison, both systems used the same line length (150 m), and hauling speed was calculated based on this standard length to evaluate operational efficiency differences.

- For conventional systems:

$$V_m = \frac{150}{975} = 0.15 \text{ m/s}$$

- For modified handlines:

$$V_a = \frac{150}{610} = 0.24 \text{ m/s}$$

Operational speed increased by 60%, from 0.15 ± 0.03 m/s to 0.24 ± 0.01 m/s. Statistical comparison also confirmed significant improvement in hauling performance ($p < 0.001$), showing that the mechanical-electrical handline significantly improves hauling efficiency. Faster hauling enables more fishing operations per trip, potentially increasing productivity, while also reducing fisher fatigue and improving safety. Thus, operational speed is a key indicator of the effectiveness of this innovation in reducing dependence on human labor.

TABLE II. STATISTICAL COMPARISON OF HAULING PERFORMANCE

Parameter	Conventional	Modified
Hauling time (s)	976 ± 188	610 ± 7
Speed (m/s)	0.15 ± 0.03	0.24 ± 0.01
Sample size	48	5
p-value	multicolumn{2}{c}{ $p < 0.001$ }	

A. Labor Efficiency in Modified Handline

One of the main objectives of developing the proposed handline was to reduce dependence on human labor due to physical limitations and increasing difficulty in recruiting fishing crews. Conventional handline operations require six crew members for manual hauling, while the mechanical-electrical system requires only two (an operator and a bait handler) because the hauling process is assisted by an electric motor. The following section presents the labor efficiency calculation.

Given $N_m = 6 \text{ men}$, $N_a = 2 \text{ men}$, $E_t = \frac{6-2}{6} \times 100\% = 66.7\%$. This means that the modified handline fishing gear can reduce labor requirements by up to 66.7% without significantly reducing catch yields.

B. Comparison of Labor Usage Between Conventional and Modified Handline Systems

Fishing gear efficiency is influenced not only by catch but also by labor requirements and task distribution. Differences between conventional and modified handlines affect crew size and workload. Technological advances can reduce crew numbers and change task allocation through gear modernization [13]. Therefore, a comparative labor analysis was conducted to evaluate the effectiveness of the modified system (Table III).

TABLE III. NUMBER OF WORKERS AND DIVISION OF TASKS IN THE CONVENTIONAL HANDLINE FISHING

Job components	Conventional System (men)					
	1	2	3	4	5	6
Fishing line puller (hauling)	✓	✓	✓	✓	✓	✓
Bait	✓	✓	✓	✓	✓	✓
Catch carrier	✓	✓	✓	✓	✓	✓

TABLE IV. NUMBER OF WORKERS AND DIVISION OF TASKS ON MODIFIED HANDLINE FISHING RODS

Job components	Modified system (men)	
	1	2
Fishing line hauling operator	✓	-
Bait	-	✓
Catch carrier	✓	✓

Field observations (Tables III & IV) show a significant difference in labor requirements between conventional and modified handline systems. Conventional hauling requires six fishers, while the modified system requires only one operator due to the use of an electric motor, reducing manpower by 83.3% at the hauling stage. Bait searching still requires human labor, with six crew members involved in the conventional system and only one in the modified system. Fish handling after capture still involves all crew members in both systems because it depends on physical strength. Overall, the modified system reduced total crew requirements from six to two per operating cycle, demonstrating its potential to improve labor efficiency, reduce operational costs, and lower physical workload without reducing fishing effectiveness.

IV. CONCLUSION

This study demonstrates that the proposed electric handline system significantly improves operational efficiency in small-scale tuna fisheries. The integration of an electric motor and IoT-based monitoring system reduced hauling time from 976 ± 188 s to 610 ± 7 s ($p < 0.001$) and increased hauling speed by approximately 60%, indicating a substantial improvement in hauling performance. In addition, labor requirements were reduced from six to two crew members, corresponding to a labor efficiency improvement of 66.7% and significantly lowering the physical workload on fishers. These findings highlight the potential of integrating mechanical and digital technologies to address labor shortages and improve safety and productivity in small-scale fisheries. The proposed system offers a practical and applicable solution for enhancing fishing operations without fundamentally changing traditional fishing practices.

However, it is important to note that the results of the modified system are based on a limited number of observations ($n = 5$). Therefore, the findings should be interpreted as preliminary results, and further validation is required before drawing more generalized conclusions. Future research should involve larger sample sizes, longer-term field trials under varying environmental conditions, and comprehensive evaluations including economic feasibility and catch performance. These efforts are necessary to support the wider adoption and optimization of the proposed system in small-scale tuna fisheries.

DECLARATIONS OF COMPETING INTERESTS

The authors declare no competing interests or personal relationships that could have influenced the results of this study.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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