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State Of The Art Of Cyber-Physical System For Monitoring And Tracking In Maritime And Fisheries Sectors

State of the Art Sistem Siber-Fisik Untuk Pemantauan Dan Penelusuran Jejak Di Sektor Maritim dan Perikanan

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Abstract: This article presents the state of the art of research and publications regarding cyber-physical systems which include theory and working systems as well as applications in the maritime and fisheries fields. The literature collection method is based on keywords sourced from books, dissertations and theses, scientific articles, and website pages. The results presented in the form of descriptions and illustrations based on work systems that include construction, communication, computation and control. This review is important to increase a comprehensive understanding of the concept and implementation of cyber-physical systems in the maritime and fisheries sector.

Abstrak: *Artikel ini menyajikan penelitian dan publikasi terkini mengenai sistem cyber-fisik yang mencakup teori dan sistem kerja serta aplikasinya di bidang kelautan dan perikanan. Metode pengumpulan literatur didasarkan pada kata kunci yang bersumber dari buku, disertasi dan tesis, artikel ilmiah, dan halaman website. Hasilnya disajikan dalam bentuk deskripsi dan ilustrasi berdasarkan sistem kerja yang meliputi konstruksi, komunikasi, komputasi dan pengendalian. Kajian ini penting untuk meningkatkan pemahaman komprehensif mengenai konsep dan implementasi sistem cyber-fisik di sektor kelautan dan perikanan.*

INTRODUCTION

The advancement of science and technology that characterizes the state represented by the creation of intelligent, virtual, and digital performance models in large-scale industries is known as the Industrial Revolution 4.0. The integrated structures found throughout the industry and possible technologies in numerous industrial activity domains are features of the 21st-century industrial model. The technology employed is a fundamental component of the 4.0 industrial design principles, which are in charge of guaranteeing the industry's inventive performance across a range of industries (IntechOpen, 2020).

Among the technological subfields contributing to the advancement of the industrial revolution is cyber-physical systems. 4.O. It is imperative for researchers, practitioners, policy makers, system designers, administrators, managers, and policy makers to create thorough and current research and information resources on cyber-physical systems (CPS). Cyber-physical systems are real-world systems that are operated throughout time and designed to support human labor. When certain activities, such computing, communication, and control over physical processes, interact with one another and provide feedback, a device becomes a cyber-physical system (Chazon, 2019). In another it is an integration of communication, computation, control and physical elements. At present time, CPS is one of the center of attention for academia, government, and industry.

METHODS

Collection of literature searched based on keywords and content lists from various sources such as books, theses and dissertations, scientific articles, technical reports and website pages. Relevant statements and illustrations are extracted, adapted, and presented and described in a new information presentation to enrich insight into the theory and application of cyber-physical systems in the maritime and fisheries sector.

RESULTS AND DISCUSSION

The results and discussion of cyber-physical systems (CPS) will cover design, concept, and theory consisting of construction, communication, control systems, and computation. The CPS applications collected and discussed consist of applications that have been carried out by the public sector (government), non-government sectors, and research and education institutions. The field of application is limited to the fisheries and marine sectors, especially for monitoring the aquatic environment, ship tracks, and aquaculture.

The term “cyber-physical systems” emerged in 2006, first used by a researcher Helen Gill at the National Science Foundation in the US. It is true that the terms "cyberspace" and "cyber-physical systems" share the same etymology, called "cybernetics.". On the other hand, American mathematician Norbert Wiener (Wiener, 1948) is credited with coining the term "cybernetics" and greatly influenced the growth of control systems theory. The junction of the physical and the cyber is the subject of CPS, an intellectual issue (Lee & Seshia, 2017).

Cyber-Physical Systems (CPS) is the integration of cyber components contained with physical components. Information technology, virtual reality, and computers are all included in the word "cyber" (Raisin et al., 2020). Cyberspace, on the other hand, is a synthesis of worldwide digital networks. All digital communications, including isolated networks and esoteric, antiquated communication protocols, are included in this system. It also comprises an interactive realm for information storage, modification, and communication made out of digital networks. Not only is the internet used to operate cyber systems, but other information systems do as well. Stated differently, the complete CPS "central nervous system" is represented by the cyber component (Clemente, 2010). On the other hand, physical components are things that are subject to physics' laws. Mechanics, optics, electromagnetics, and thermodynamics are among the physical elements that are crucial to the design of CPSs. These elements are frequently present even in the cyber (computational) components of a CPS. One common theme in both mathematical and physical modeling is the presence of conservation laws. Mechanical system examples include: 1) Energy conservation, 2) momentum conservation (rotational and translational), and 3) mass conservation. The primary illustration from electrical systems is: 4) Current conservation (Taha & Thunberg, 2021).

The electronic systems that make up CPS are distinguished by their size, cost, computational capacity, and power consumption (Montagny, 2021). Our interactions with the physical world have evolved as a result of CPS, from detecting environmental factors to managing intricate manufacturing sectors. The present paradigm change in design and manufacturing places more emphasis on innovation, cost-effectiveness, customer demands consideration, best practices, intelligent systems, and alternatives to on-demand production (Saldivar et al., 2015).

Cyber-Physical Systems (CPS) are the next wave of embedded intelligent information and communication technologies. They are autonomous, cooperative, interconnected, and monitor and control physical components and their processes for a variety of applications. Future CPS must be decentralized, scalable, and distributed to enable interaction with people, the environment, and machines while being linked to the Internet or other networks. These systems should have properties like adaptability, reactivity, optimality, and security because CPS are increasingly creating an unseen "neural network" throughout society (Vermesan, 2024). In this article provide description of the design system that consist of construction, communication, control and computation. Composition is related to hardware architecture constructed of electronic components such as smart sensors and microcontroller chips. The communication used is a wireless network, control system is software embedded in hardware, computing related to data acquisition and post-processing.

1. Construction/architecture

1.1 Smart Sensor

In the mid-1980s, the term "smart sensor" first appeared. Many products under this designation do contain intelligence created by multiple semiconductor manufacturers. The Digital signal processors (DSPs), field programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), and microcontroller units (MCUs) all use this concept.. The sensor or transducer converted measured physical quantity into displacement. As shown in Figure 1(A), the observer starts a system correction to fix the reading and bring it closer to the desired value. Excitation from a sensor or transducer that uses resistive, capacitive, and inductive sensing elements is required to produce the output. As shown in Figure 1(B), factors that affect the sensor's accuracy and performance, such as intended input and undesirable environmental impacts, must be considered during the design process.

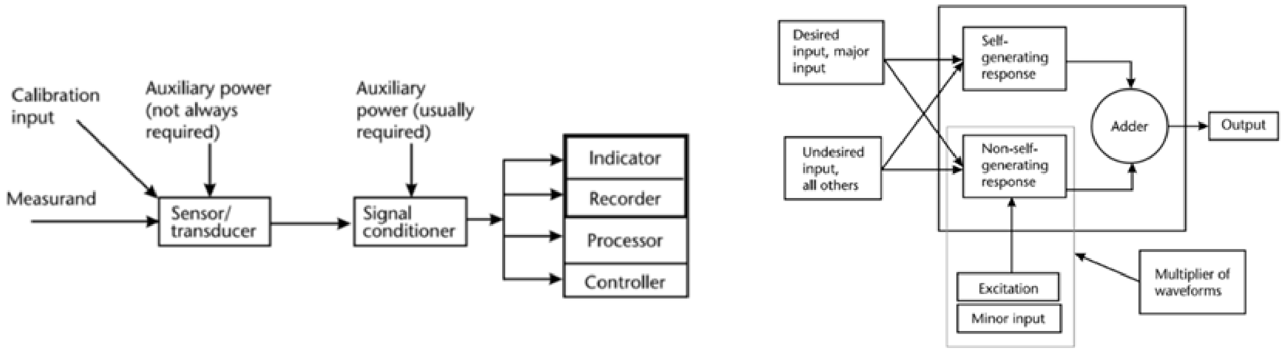

Figure 1(A) Generic sensing system, and (B) Generic sensor/transducer model
Source: (Frank, 2013)

From a broader perspective, a smart sensor system is a fully autonomous sensor system that can log, process data using sensor response models and other sources, provide self-sufficient power, independence and the capacity to show external users with useful information (Hunter et al., 2012). A smart sensor integrates multiple components, including memory, controller, power supply, ADC, signal conditioning, and amplification. Since the sources featured an invertor, interaction and data transmission with several communication protocols are permitted once the signal has been converted to digital representation. In the meanwhile, system design addresses power management concerns and how they affect system accuracy (Frank, 2013). A data collection, recording, or acquisition system external to the smart sensor system will require an electrical link to transfer the sensor outputs. Using wireless telemetry techniques, this interface can ideally be wire-free (Hunter et al., 2012).

1.2 Microcontroller

A microcontroller serves as the main source of control in many embedded systems used in electrical and computer engineering applications (Russel, 2010). A microcontroller is a single integrated circuit tiny computing system. These electronic parts are made with specialized, devoted functions in mind, meaning they shouldn't ever require reprogramming. Microcontrollers are sufficient for carrying out operations like interpreting sensor data and applying control rules (Lambert, 2017). Sensor system model illustrated as shown in Figure 2.

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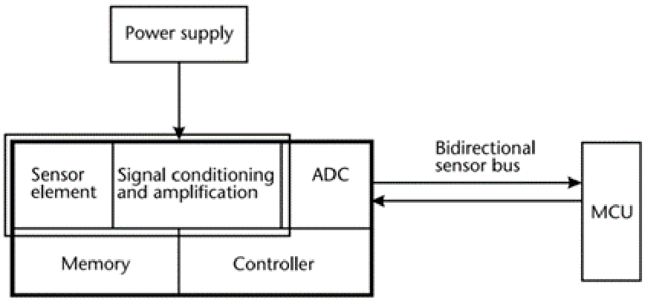

Figure 2. Sensor system model
Source: (Frank, 2013)

2. Communication

Cyber-physical systems include communication systems (Figure 3) that are enhanced by their inherent characteristics, which include covering large areas, including inaccessible locations and frequently functioning in hostile settings. The most recent development is the widespread employment of wireless technology in control and monitoring applications, which is motivated by its indisputable benefits. When it comes to cost saving, the replacement of cables is involving some advantages such as the ability to operate in various network topology, scalability and lower maintenance efforts (Moiset al., 2015).

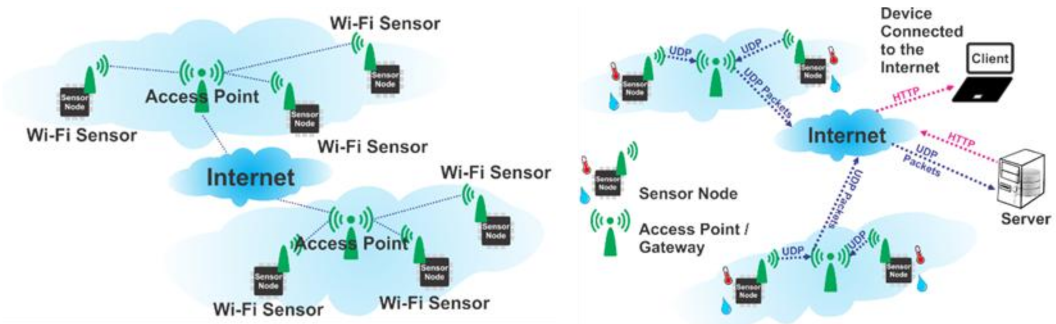

Figure 3. A) Access Point Network, and B) Access Point Architecture

Wireless communication technology for Internet of Things protocols is available at no cost and does not require authorization, utilizing certain free frequency bands. (Montagny, 2021). Technology for cable or wireless communication is used in the physical cum data-link layer. Technologies such as NFC, RFID, ZigBee, Bluetooth (BT), RF transceivers, and RF modules are examples of wireless communication. These wireless communication methods are described in the subsections that follow. 1) An improvement on the ISO/IEC2 14443 standard for contactless proximity cards is called Near-Field Communication, or NFC. NFC is a wireless communication technique with a small range of 20 cm. It enables data exchange between cards in proximity and other devices. 2) RFID is the biggest power consumer in wireless sensors or actuators, this being the reason for keeping its operation to a minimum (Mois et al., 2015).

The term "Internet of Things" (IoT) refers to the idea of physical items, or "things," interacting with one another via the use of internet-working devices and apps. Things categorized as identity communication devices are where the idea of the Internet of Things originated. The concept of IoT began with things classified as identity communication devices. Radio Frequency Identification Devices (RFIDs), which are tagged to the device for identification, are an example of this term. Using distant PCs connected to the Internet, the RFID-designed device can be tracked, managed, and observed. IoT is, in theory, the integration of the Internet, controllers, sensors, actuators, and physical objects.

3. Control

Managing the connections between physical processes and computing algorithms is a crucial component of control. The three main concepts of known control are feedforward, adaptive, and feedback control. As seen in Figure 4, its primary components are a sensor, interface, software, and power supply.

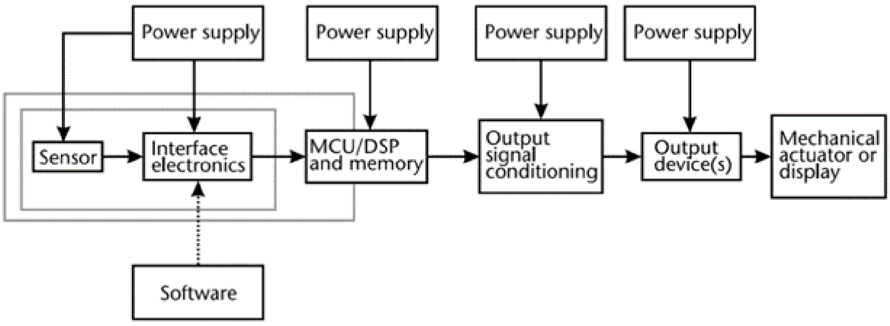

Figure 4. Generic control system

Issues with intricately designed industrial and technological devices fall under the category of intelligent control, which necessitates making judgments in the face of ambiguity. Intelligent control technologies based on knowledge will be essential to the industry's future growth. These technologies make use of techniques, models, and algorithms that gather and extract the knowledge required to identify the best course of action. The foundation of intelligent control theory is the ability to learn about the environment and adjust as needed to achieve the intended outcome. Stated differently, the core concepts of contemporary control system theory are artificial intelligence and intelligent systems.

4. Computation

The implementation of CPS technology facilitates the creation of a ubiquitous computing environment; therefore, processing massive volumes of data generated in and flowing through such a diverse and dispersed environment requires unique considerations. Big Data processes including data collecting, filtering, transmission, and analysis must be changed to meet these criteria, along with other data management and analytics methods (Buyya & Dastjerdi, 2016)., to some extent. Large volumes of recorded data necessitate a high level of computational power and skill. To better convey data patterns in infographics that aid in knowledge acquisition, a number of techniques have been created. moving on to

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artificial intelligence from more traditional techniques like statistics.

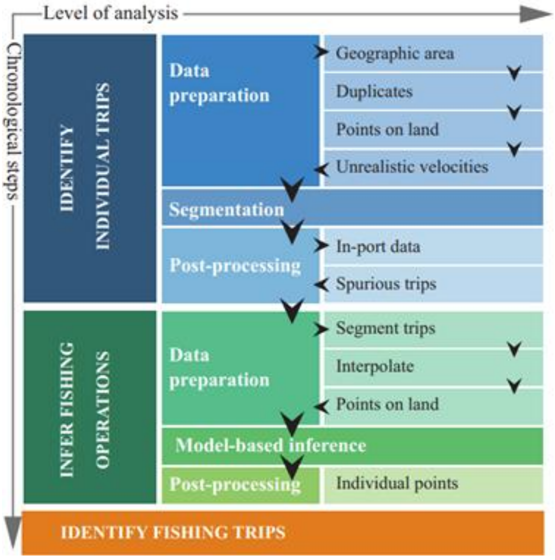

Table 1. Description of the user-input variables.

Parameter	Units	Definition
cum_dist	metres	Cumulative distance from trip extreme points
crs_wgs84	EPSG	EPSG code for WGS84 CRS
crs_utm	EPSG	EPSG code for UTM projected CRS
d_interp	metres	Minimum distance between points to interpolate
dist_travelled	kilometres	Minimum length of a trip
lat_max, lat_min	decimal degrees	Latitude boundaries
lon_max, lon_min	decimal degrees	Longitude boundaries
n_obs	number	Minimum observations for a valid trip
port_buffer	metres	Distance within the port where points will be discarded
speed_filter	knots	Maximum allowed speed for vessels
time_travelled	hour	Minimum duration of a trip
t_interp	minutes	Time interpolation between points

Figure 5. A) Workflow showing sequential steps to identify fishing trips, and B) Description of the user-input variables. Source: (Mendo et.al., 2024)

2. Cyber-physical system for Monitoring and Tracking in Maritime and Fishery Sectors

Monitoring and tracking are important key factor in marine resource management. Sustainable fishery management can be achieved by increasing knowledge with some efforts such as collecting data as stated in the Fishery Law, for example, No. 31/2004, chapter 1 article 7 that “Fisheries Management means all undertakings, including integrated process in collecting information, analysis, planning, consultation, decision making, allocation of fish resources, and law implementation and law enforcement of legislation in the field of fisheries, performed by the government or other authority which are directed to achieve sustainable waters biological resources productivity and agreed objectives”.

2.1 Environment and Climate Change

Applications of CPS in science include wave measuring, oceanography, meteorology, climate science, and algal tracking. Industrial uses include wave measurement, oceanography, meteorology, transportation, subsea communication, visual inspection, emissions monitoring, fisheries management, and aquaculture. Environmental stresses include wear, corrosion, and conditions that include a lot of mechanical forces. For extended periods of time, an unmanned vehicle intended for autonomous operation must endure the severe conditions found at the sea's surface.

NASA has made available real-time environmental data obtained from buoy devices and satellites. The instrument, which is equipped with a sensor, microprocessor, data logger, solar panel, and batteries, is depicted in Figures 6(a), 6(c), 6(b), and 6(d). The depiction of the instrument movement was displayed in Figures 1b and 2b. NASA conducted this study, and USNA conducted the tests. Modifications to the engineering design were made to increase thrust, stability, and maneuverability. The platform underwent an evolution that resulted in a more compact design with an integrated, modular component system and enhanced functionality (USNA, 2017).

The SailBuoy gadget in Figure 6 functions through a wind-driven platform and exhibits characteristics akin to those of a sailboat. The SailBuoy navigates by tacking to make headway against the wind and get closer to the user-defined waypoint, much like a conventional sailing boat. The SailBuoy communicates measured parameters and diagnostics over the Iridium satellite system. A versatile offshore sensor platform that can accommodate a range of instrumentation payloads is called SailBuoy. It can move from one place to another or stay on station. Satellites are used to transfer data in real time to and from the shore.

Given that Iridium is a two-way communication system, the vessel in motion can receive directives such as new tracks, waypoints, and sensor information. Actuators and onboard electronics are powered by solar panels and batteries. Access to a website is granted in order to manage Sailbuoy. Waypoint updates and Sailbuoy data downloads are available there. User friendliness has also been given top emphasis here. The majority of the time is spent, according to experience, keeping an eye on the Sailbuoy's progress during the expedition. The website has also been optimized for mobile use. To manage and track the Sailbuoy's movement, the operator can log in here. The same interface is used by the payload communication for both control and data retrieval. With its sensor, control, and power system, the kayak hull can navigate at sea for several months. Modular payload that supports a wide range of sensors, such as Sidescan sonar, Fishfinder and Chartplotter, modularity, and sensor integration. Enhancements to thrust (speed, acceleration, and towing capability), stability (limited pitch, roll, and yaw), and real-time remote desktop piloting were among the other design objectives.

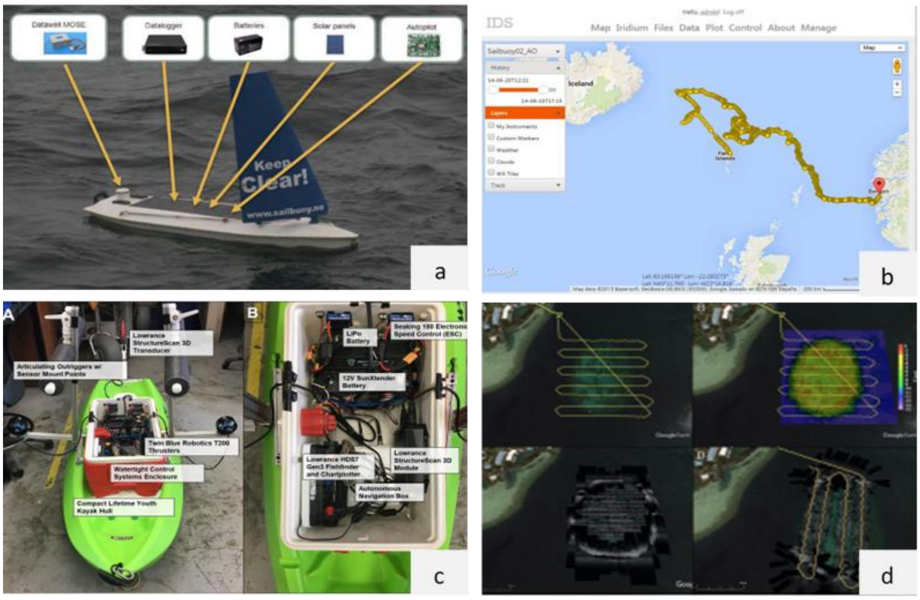

Figure 6. Example of instrument of environmental measurement with movement visualization

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2.2 Fishing Operation

Integrating and employing electronic technologies to read and regulate a ship's movements from one location to another is the process of navigation. The position chart is automatically updated with data from many ship sensors by integrated systems, which also send out the control signals needed to keep a vessel sailing on a predetermined path. Choosing system settings, deciphering system output, and keeping an eye on vascular reaction transform the navigator into a system manager (Morsi et al., 2015). Many features, including Automatic Positioning System (Figure 7), Automatic Identification System (AIS), Vessel Monitoring System (VMS), Vessel Traffic System (VTS), Electronic Recording System (ERS), FMS, FAD, etc., are specific to the Navigation Platform, which has been developed and implemented successfully in various parts of the world (Nazzla, 2016). Though the foundations of all the systems listed are identical in theory, there are some variances, particularly in the more specialized implementation. Numerous locations across the globe are home to certain research and development activities. As can be seen below, this article has summarized a few of the significant ones.

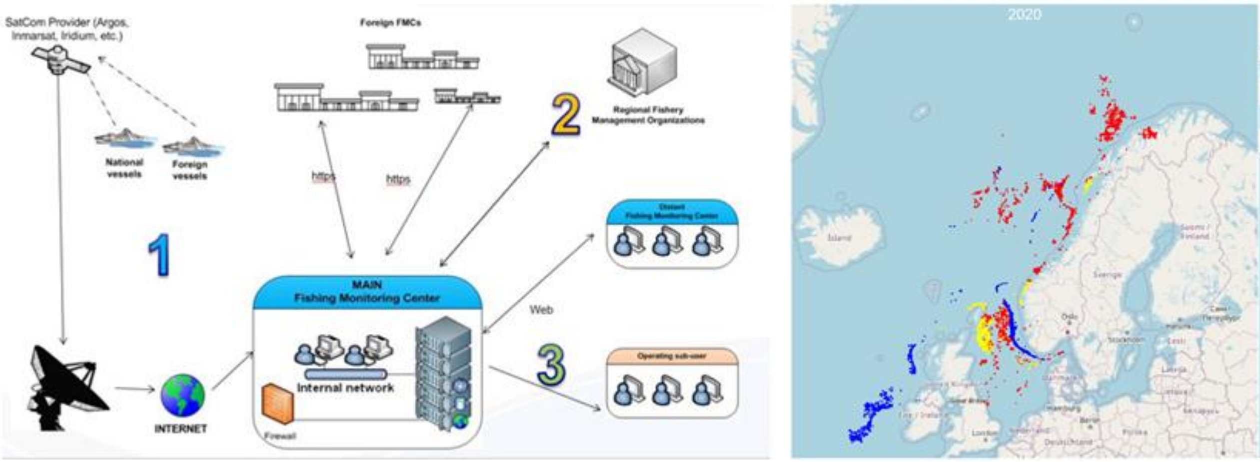

Figure 7. Example of Automatic Positioning System Framework and Visualisasi
Source: (A) Maritime Survey, 2024 and (B) Ottera, et al., 2023

2.3 CPS Implementation of Fishing Operation in Indonesia

2.3.1 Government Program

According to Marine Survey (2024), there are two parts: the system on land (a contemporary platform like a smartphone) and the system on board (a connected server). These will be incorporated functions that improve fishing management and surveillance skills while boosting catch analysis efficiency. A VMS system known as the Fisheries Vessel Monitoring System (SPKP) was implemented by PSDKP KKP in 2018. An application that encourages participation is also available for this tool (Figure 8). One example of a gadget that implements the entire CPS concept is a smartphone that has software installed that includes visualization capabilities.

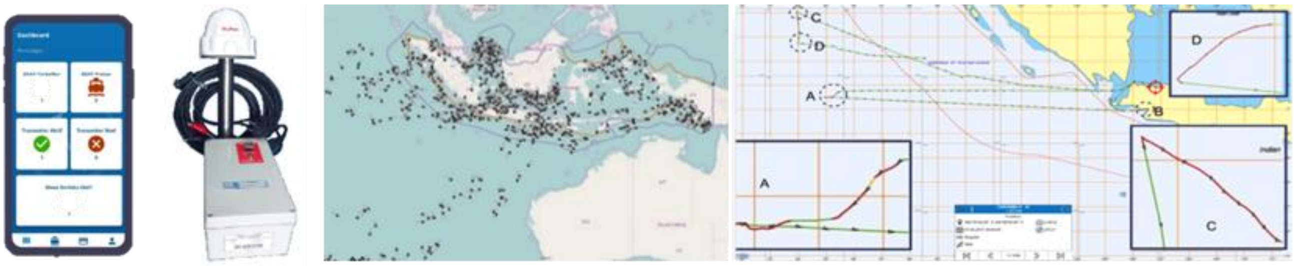

Figure 8. A) Salmon Apps and Vessel Monitoring System, and B) Visualization of VMS Data Analysis

Fish Aggregate Device, GPS tracker, etc, are example of instrument as an effort of government to obtain fish catch information. The components of the adaptive management framework in fisheries management include data gathering, stock assessment, management practices, creation and application of management measures, monitoring, and assessment. Visualization of the MITC-L (Marine ICT-Landing) digital catch landing data recorder using IoT is illustrated in Figure 9 (Natsir et al., 2022).

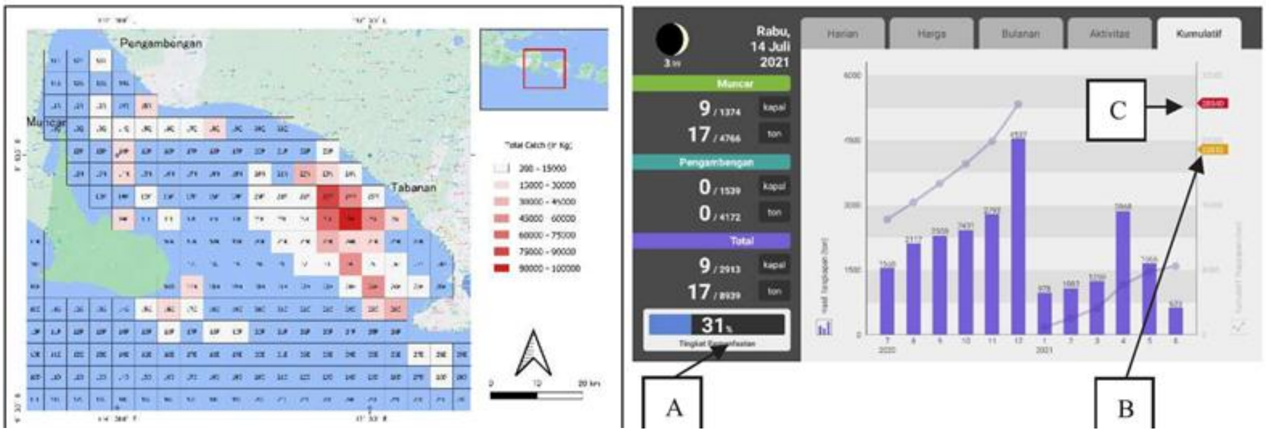

Figure 9. Visualization of MITC-L 2.3.2 NGO Program

In order to manage fisheries responsibly, traceability is crucial. Information technology advancements are critical to the execution of the idea of product traceability and the attempts to keep illicit goods out of the legal supply chain (MDPI, 2020). TraceTales is a new product that this foundation has introduced (Figure 10). The TraceTales system is currently being used by six Fish Processing Units (UPI) within MDPI work areas, and these units have produced over 5,500 tons of traceable tuna products.

Figure 10. Ilustration of NGO contribution in maintaining sustainable fisheries, supply chain, and society

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2.3.2 Research and Development for Monitoring and Tracking using CPS concept

A prototype is an actual, working example of the model (Figure 11). Because of this, testing can begin sooner and allow for qualitatively different validation than can be accomplished by analysis or calculation. Prototypes can be used to test the notion of a product's safety as well as how users react to it after using it firsthand (Taha & Thunberg, 2021).

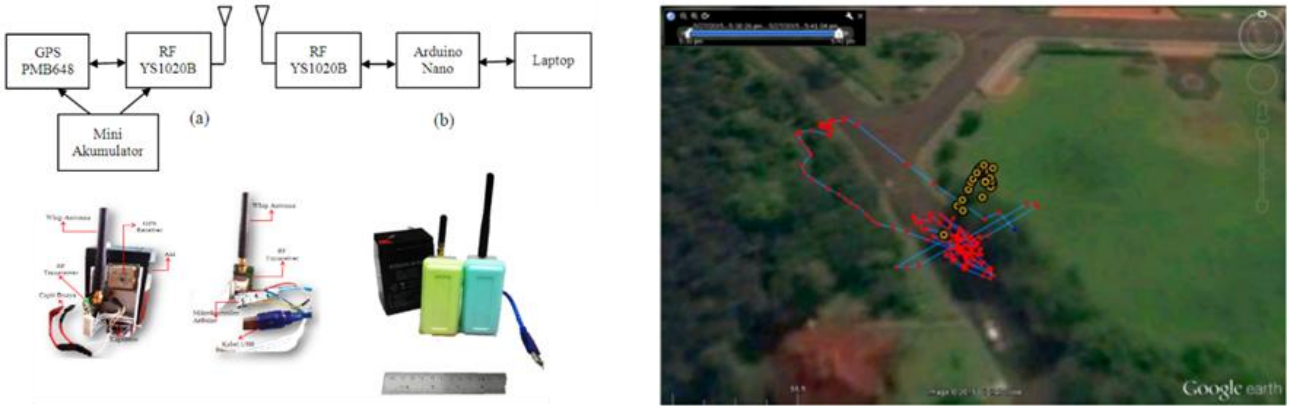

Figure 11. (A) Architecture of electronic circuit and prototype result and (B) Visualization. Source: Nazzla et., al. (2016)

Basically, communication between one device and another can use any radio waves spectrum depend on requirements. Nazzla (2016) has produced a prototype by utilizing radio frequency 433 Hz as a simple communication system that allows data transfer from sensors that act as trackers to sensors that receive data to be stored with devices that have the capacity to store data. The resulting electronic circuit consists of one transmitter and receiver unit each which has its own function. The transmitter consists of one GPS receiver module element, one RF transceiver module, one antenna, and a 12V power supply. The GPS contained in this unit functions to receive coordinate data in NMEA format and store it so that it can be transmitted by RF in real time. The other units are an RF receiver and microcontroller which functions to control the overall working system and is equipped with a USB cable for data transfer. Along with the increasing development of communication technology, this prototype needs to be developed to minimize distortion. Nazzla et al., (2023) stated that the accumulation of several factors that cause distortion in GPS is caused by a number of dominant contributors and contributors who are thought to be influential.

The other application in the fisheries sector that has been developed is a fishing tracking tool called TREKFish developed by Laboratory of Marine Acoustics, Instrumentation and Robotics at IPB University (Kompas, 2020). Jaya et al., (2019) on Sustainable Fisheries Partnership technical report stated that this tool aims to trace the track of fishing (such as fish, crab, lobster) and is equipped with fisher software (Fisheries Electronic Reporting). This instrument was designed and developed to support the Seafood Import Monitoring program (Panrita, 2019). This instrument is included in the VTS (Vessel Tracking System) category (APRI, 2021). The instrument architecture is composed of a GPS

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sensor, microcontroller, and power supply. The data communication system uses an IoT-based system. The control system regulates the time interval for recording and transfering data. This instrument is set to record the ship's position every 5 minutes or 12 points/hour and sends real-time data every hour. Position data is sent utilizing cell phone signals and is equipped with solar panel technology for charging. The resulting data involves post-processing analysis to track fishing operations based on transit time (Trekfish, 2017). Apart from that, data can be obtained to present information in the form of distribution maps of main catches, by-catch, and CPUE. The instruments and visualization as shown in Figure 12 below.

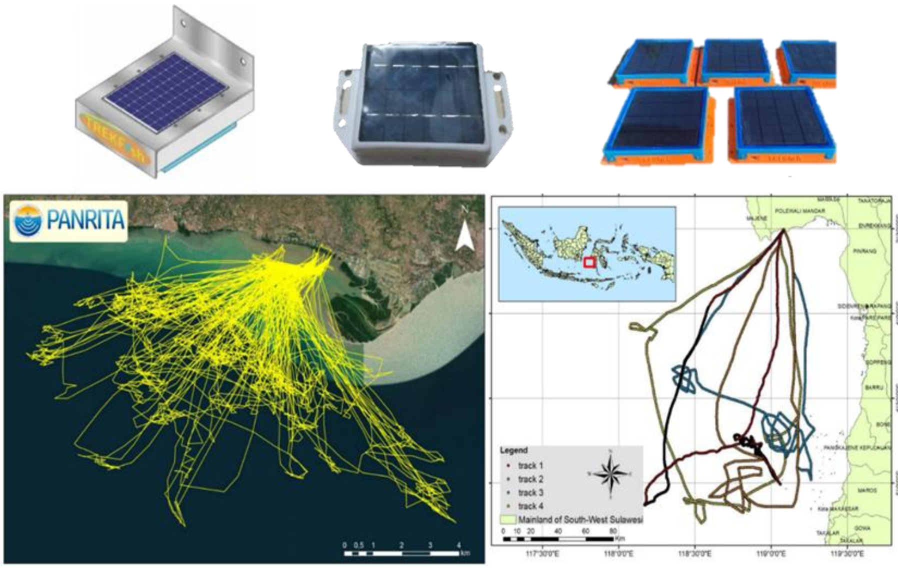

Figure 12 (A) Instrument and (B) Visualization of Trekfish
Source: (A) Jaya et.al, 2019, (B) Putri, Jaya, Agus, Pujiyati, & Palo 2024

2.3 Aquaculture

Aquaculture, sometimes referred to as aquafarming, is the raising of fish, algae, and other organisms in different types of water environments for the purpose of growing, reproducing, and harvesting them. Put differently, regulated conditions are utilized to produce both freshwater and saltwater fish populations. Aquaculture growers were having trouble maintaining the water's quality, feeding the crops, and diagnosing illnesses (Manoj & Rajan, 2021). Farmers involved in aquaculture were having trouble maintaining the water's condition, providing food, and recognizing illnesses (Manoj & Rajan, 2021). Aquafarmers may find that the time-consuming manual testing methods they use to evaluate the status of the water parameters and identify diseases are not very efficient. It might also produce unintended outcomes. Automated aquafarm monitoring can help to improve the problem. Several contemporary technologies can be used to solve these issues. Numerous important aqua farming application areas, including living quality, early illness detection, safety, fish feeders, water quality monitoring, environmental changes, etc., require the help of technologies. A microcontroller, sensors, pumps, and other system

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components are all connected in a single block as part of the system architecture (Bachtiar et al., 2022).

A smart aquaculture system integrates a number of smart devices into a specially designed habitat to monitor cultivated environmental parameters in real time and automatically makes decisions based on the data it collects (Sharma & Kumar, 2021). Intelligent aquaculture is linked to intelligent production modes. Using IoT, it may be operated remotely. Additionally, an automated system (robot) that can handle buildings, machinery, and equipment to run entire systems and produce successful production can be used to control smart aquaculture (Vo et al., 2021).

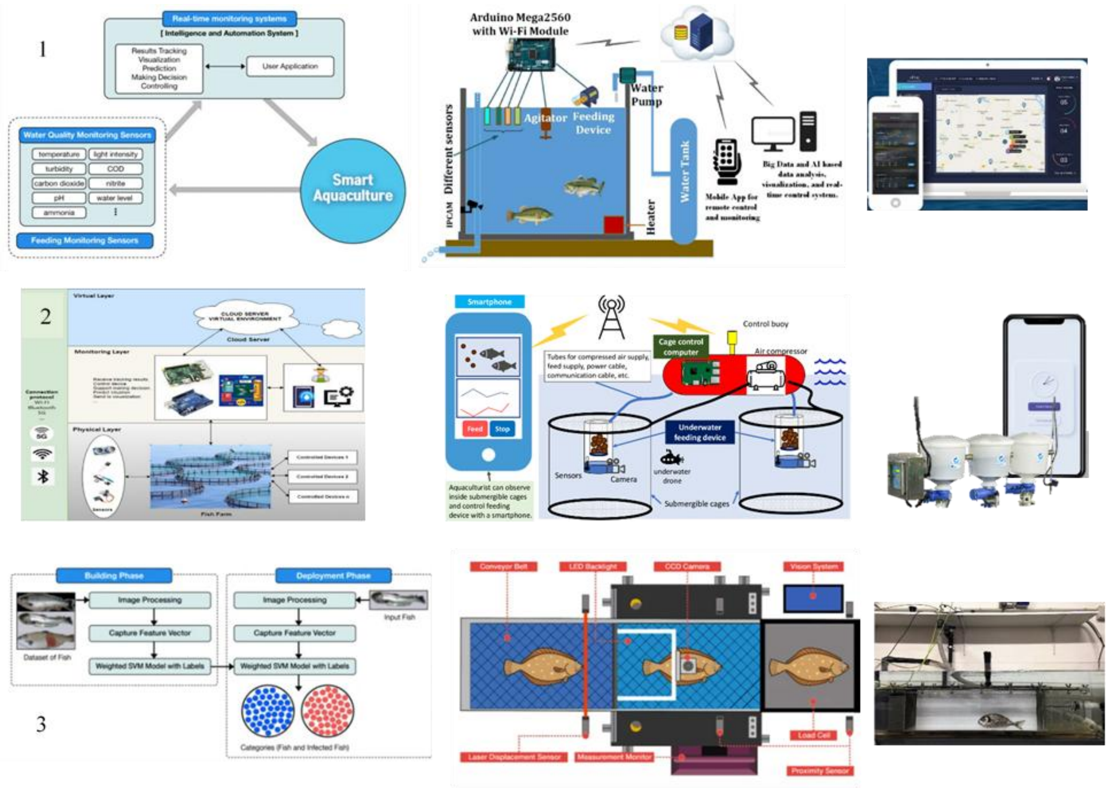

Figure 13 A) CPS System, B) Design, & C) Product of 1) Water quality monitoring, 2) automatic feeder, and 3) Disease identifier

Aquaculture frequently faces issues such as overfeeding fish, which wastes food and contaminates the water. On the other hand, feeding fish too little can stunt their growth. Using an automatic feeder is one way to solve issues with hand feeding as well as the consequences of overfeeding and underfeeding. The precise measurements used in the design of this feeding machine will assist lower labor and time expenses, which will lower the total cost of feeding. Fish size and species are taken into consideration in the design. Using a motor and timer connected to the food dispenser, this unit will dispense a set amount of food at a predetermined time (Manoj et al., 2021).

Another common problem in aquaculture is disease which results from the imbalance among many factors which come from host, pathogen and environment. There are different types of disease which is illustrated in two main categories: infectious

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(parasitic, fungal, bacterial, viral) and non-infectious (environmental, nutritional and genetic), (Rahman et al., 2019). It is challenging to implement prompt and efficient treatment methods when a sudden fish disease cannot be accurately treated by farmers. Fish disease detection device is one of solution developed to overcome the issue. It required sensor to recognize indication of fish in early stage and embedded with artificial intelligence. The system controlled and monitored by IoT system.

Other research related to aquaculture using IoT concept is the development of photobioreactor instruments for microalgae cultivation, Rahmat et al. (2020) used IoT technology which is composed of hardware consisting of sensors, microcontrollers, data loggers, and software embedded in the control system and applied to displays the data. The communication system used is cyber-physical interaction, which is a characteristic of an IoT system, indicating that all of the detected parameters are shown, in this case through a graphical user interface (GUI), through a back-and-forth link between the physical phenomena being watched and the web server, which serves as the control interface with the internet.

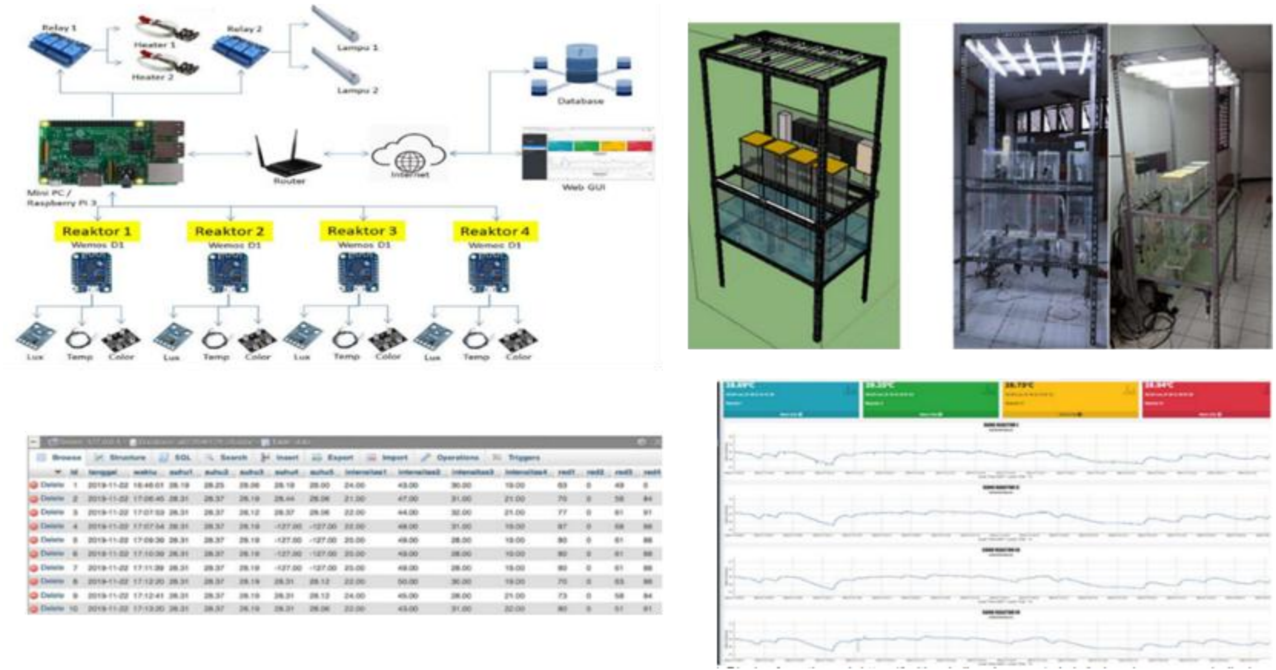

Figure 14. Research and Development of Photobioteactor in Microalgare Cultivation (Rahmat et al., 2020)

CONCLUSION

Theory, working principles and design are interrelated so it is important to understand them in order to design an effective, cost-effective, and efficient system. Cyber-physical system technology can be utilized and developed in the marine and fisheries sector as an effort to optimize the achievement of responsible marine resource management.

RECOMMENDATION

There is a need for an in-depth literature review on mechanics, modelling, network systems cyber-physical. As well as additional literature review on underpin research in the field of fisheries and marine affairs.

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