# Design, development, and deployment of a sensor-based aquaculture automation system

**Sasikumar R**
Bharathidasan University
**Lourdu Lincy L**
Bharathidasan University
**Anish Sathyan**
Centre for Development of Advanced Computing
**Chellapandi P** ( pchellapandi@bdu.ac.in )
Bharathidasan University

---

**Research Article**

**Keywords:** Automation, Sensors, Shrimp, Biofloc, Probiotics, Controller, Water quality

**Posted Date:** February 14th, 2024

**DOI:** https://doi.org/10.21203/rs.3.rs-3950663/v1

**Additional Declarations:** No competing interests reported.

---

# Abstract

The aquaculture automation system (AcAS) is a user-friendly single-window unit. This allows end users to easily monitor and control the entire system through a built-in, customizable graphical user interface. AcAS was designed for simplicity, making it easy to configure and use. This system was integrated with highly efficient industrial-grade environmental sensors (pH, conductivity, oxidation-reduction potential and dissolved oxygen) to ensure precise and error-free results in harsh environments. It can also store the user and system data in an attached memory device. It is equipped with built-in Wi-Fi, LoRa/ZigBee, and 4G/5G modules for data transfer, making it compatible with modern communication technology. It was programmed to be farmer-friendly and helped farmers maintain optimal shrimp growth conditions by monitoring various parameters. AcAS takes corrective measures as required, and provides updates to farmers through a graphical display unit. Additionally, farmers can configure devices to receive alerts regarding important field parameters or alarm conditions. Therefore, AcAS enhances the efficiency and sustainability of aquaculture farming by enabling precise control of farming conditions and proactive management of aquaculture.

# Highlights

- AcAS is a user-friendly unit that allows easy monitoring and control.
- It is integrated with industrial-grade environmental sensors
- AcAS is equipped with communication modules for data transfer.
- It helps farmers maintain optimal shrimp growth conditions.
- Farmers can configure devices to receive alerts.
- It enhances the efficiency and sustainability of aquaculture farming.

# Introduction

The aquaculture industry, set to grow at a 7.5% CAGR from 2020 to 2027, has seen the shrimp market valued at USD 45.9 billion in 2019, projected to reach USD 68.9 billion by 2027 with a CAGR of 5.2%. The industry has adopted innovative practices, such as biofloc farming, online monitoring, pond optimization, probiotics, and automation, for sustainable and profitable shrimp cultivation (Das et al. 2022; Yu et al. 2023). However, challenges persist in shrimp grow-out ponds owing to fluctuating environmental factors, poorly understood nutrient cycling, and wastewater management issues, resulting in suboptimal growth rates. Controller systems play a crucial role in aquaculture and in monitoring and controlling water quality and processes. Fuzzy logic controller systems, fuzzy rule-optimized single-neuron adaptive proportional–integral–derivative (PID) controllers, and differential evolution algorithm-optimized radial basis function neural network PID controllers have been developed to precisely track the control of dissolved oxygen (DO) in aquaculture ponds(Tang et al. 2001; Rana and Rani 2015; Haiyunnisa et al. 2017; Ye et al. 2022). An aquaculture inspection system that included a controller was used to analyze the images and determine the state of the aquaculture area (Akram et al. 2022). A multifunctional ecological regulation and control device has been developed to manage various aspects of water quality and regulations (Wang et al. 2013).

A prototype based on the Internet of Things (IoT) was developed to improve shrimp farming by monitoring and adjusting water quality. This includes a device for waste removal and a method for siphoning the pond bottom for automated waste disposal, resulting in cost savings and improved worker health (Huang et al. 2019; Huan et al. 2020; Kanagachidambaresan 2022). The system also includes a real-time surface modeling vehicle and an oxygen control system for precise farming and increased production (Agustianto et al. 2021). Furthermore, an automatic bait-feeding machine and equipment to adjust the feeding amounts based on weather conditions have been developed (Reis et al. 2021). Automation has also been applied to the diagnosis of shrimp diseases. Sensors play a vital role in automating aquaculture systems, allowing for real-time monitoring and control of various parameters and improving shrimp behavior, physiology, and environmental conditions (Biazi and Marques 2023). Solar-powered water-pumping systems for off-grid shrimp farms can be automated using ultrasonic water-level sensors and microcontrollers (Pandey et al. 2022). Intelligent aquaculture uses sensing and machine-learning algorithms for real-time data collection and automated decision-making. Online monitoring systems using wireless sensor networks (WSN) and IoT technologies have been developed to enhance productivity and maintain water quality in shrimp aquaculture (Ezhilazhahi and Bhuvaneswari, 2017;Jabeen et al. 2023). These systems monitor parameters such as temperature, pH, dissolved oxygen, and salinity in shrimp ponds in real-time, enabling shrimp farmers to take immediate preventive measures and maintain optimal water conditions. Sensor-based technologies are used for disease prevention and cost reduction.

Automation in biofloc shrimp farming greatly reduces labor and production costs, thereby boosting the financial and environmental sustainability of shrimp aquaculture. This includes innovations, such as an automatic shrimp-shelling device, computerized image analysis for assessing shrimp quality, and a device for automated shrimp decapitation. Standard feeding protocols have been established for automatic feeding systems to optimize growth rates (Chellapandi 2021). Biofloc monitoring systems, integrated with the IoT, estimate water quality parameters and provide remote access and an alarm system (Blancaflor and Baccay, 2021; Blancaflor and Baccay, 2022; Lindholm-Lehto P 2023). Despite challenges such as manual cleaning and sludge accumulation, automation offers numerous benefits such as improved water quality control, cost savings, and increased production (Alam et al. 2023). Top-dressing agents traditionally applied manually at a high cost, are now dispersed automatically by a revolutionary system based on signals from environmental and microbial sensors (Chellapandi 2021). This system also operates an aerator based on the dissolved oxygen concentration, enhancing efficiency and promoting sustainable aquaculture practices. Therefore, we designed, developed, and deployed a sensor-based aquaculture automation system (AcAS) for the Indian aquaculture farming scenario. It is a fully autonomous system that monitors and controls various parameters in aquaculture ecosystems. It operates pumps and valves intelligently, based on field data and preconfigured algorithms. AcAS collects data from multiple sensors, enabling the effective management of different control aspects. It monitors all farm parameters around the clock, ensuring optimal conditions for aquaculture and making it an invaluable tool in the sector.

## System design

AcAS is a sophisticated system built around an ARM cortex-M3-based microcontroller (SAM3X8E). It featured 12 analog inputs, 24 digital outputs, and 12 digital inputs. The system can be expanded with various boards, such as communication ports, ADC, and DAC, by using the SPI protocol (Fig. 1). It has a built-in RTC for real-time data indexing and storage on the SD Card. The motherboard was designed for low noise and precise output voltage, with separate ground layers for analog and digital circuits. Analog and digital input and output signals and their configurations are depicted in Fig. 2. The central unit has power supplies of 9V, 5V, 4V, 3V, and 3.3V for different components. A touchscreen TFT display with a GUI allows users to configure the unit and set the parameters for farm control and monitoring. It has a high-performance, 32-bit ARM Cortex-M3 RISC processor. It operates at a maximum speed of 84 MHz and features up to 512 kB flash memory and 100 kB SRAM. The peripheral set included a High-speed USB port, an Ethernet MAC, 2x CANs, a High-Speed MCI for SDIO/SD/MMC, an External Bus Interface with NAND Flash controller and SDRAM, 5x UARTs, 2x TWIs, 6x SPIs, one PWM timer, 9x general-purpose 32-bit timers, an RTC, a 12-bit ADC, and a 12-bit DAC. The hardware includes a processor board, GSM-SIM800L, Wi-Fi-ESP32 WROOM U32, and ZigBee-SC2 for sensor and server communication. It comprises two expander connectors with an SPI Interface. The unit had one USB connected to a serial device to communicate with the computer. The unit has one RS232 and RS485 module for communication purposes (Fig. 3).

This module features a 5-inch Graphical TFT Touch display, allowing users to configure and monitor various parameters. The display was designed using a user-friendly GUI, which simplifies the creation of control algorithms and loops. The system used the SIM800L GSM module from SIMCOM, which directly interfaces with the SAM3X8E MCU. A DTMF decoder interprets signals from the SIM800L by transferring binary data to control devices attached to the AcAS motherboard. The ESP32 WROOM 32U from ESPRESSIF was used for high-throughput data. It interfaces directly with the SAM3X8E MCU through SPI communication and operates in the low-power mode. The ZigBee SC2 module from the DIGI was used in this system. It interfaces with the MCU by using the available motherboard supply. The FT232RL IC is used to convert serial data from the MCU to USB data format, and vice versa. This feature is useful for system-level debugging and data transfers.

## Block-level design

AcAS system was powered by an external SMPS power source with an output of 12V 5A and an input of 230V ~ 50HZ. This power was converted into various voltages, including 9V, 5V, 4V, 3.3V, and 3V, using dedicated ICs for each section to ensure reliable and noise-free outputs (Fig. 4). The 9V supply powers the analog output section, where the MCU-generated analog voltage is boosted with output-amps before being sent to the output section. This results in a 9V Analog output voltage that can control the output devices. The SIM800L module was powered by a specially designed 4V power supply. This is crucial for optimal performance, particularly during the initial surge when the module is connected to a mobile operator. A TPS54335A-based power supply is used for this purpose. The motherboard's standard operations are powered by a 3.3V supply. The LTC3633A IC generates both 9V and 3.3V supplies simultaneously, providing up to 6A of output current, which is sufficient for the expected functionalities of AcAS. The system also includes a very precise 3V analog reference supply provided by LM4120AIM5-3.0 IC. The built-in TFT LCD of the GUI interface was powered by a separate TPS54335A-generated 5V power supply. In terms of inputs, the AcAS system uses the SAM3X8E MCU, which has dedicated 12-bit ADC channels for the analog sensors. A total of 24 op-amps were used in the analog section to convert the milliampere-range analog current into a voltage suitable for interfacing with the microcontroller. Each channel could be fine-tuned to ensure an accurate analog input voltage for the MCU. The system also has 12 digital inputs that are isolated and compatible with a 3.3v supply. The DI circuit ensures the isolation between the channels and external sources. AcAS module has two analog outputs that convert the voltage into the corresponding milliamps to control the external devices. The SAM3X8E has a dedicated two-channel DAC for this purpose. Finally, the AcAS is equipped with 24 digital output channels that are compatible with a 3.3v supply and can control external devices using external relays and MOSFETs.

# Software

The source code of the AcAS controller is in the SVN repository under the CIG232D -> Source code -> firmware. It was developed using Atmel Studio 7 and operates on FreeRTOS, which manages communication, I/O processing, and user interfaces, ensuring efficient and reliable operations.

# Firmware block diagram

FreeRTOS is a versatile real-time operating system with a variety of features. The kernel offers preemptive, cooperative, and hybrid configurations (Fig. 4). The code, primarily in C, is portable, compact, and user-friendly. It supports tasks and coroutines and includes powerful execution trace functionality. Stack overflow detection options are available and there are no software restrictions on task creation or priority assignment. This facilitates communication and synchronization through queues, semaphores, and mutexes. Priority inheritance is supported by mutexes. The system is royalty-free and can have a ROM footprint as small as 4.3K bytes on an ARM7 using GCC.

# Aquaculture data monitoring software

ADMS is a sophisticated tool designed to interface with an AcAS system, offering features that enhance data collection, analysis, and visualization. It uses a proprietary protocol for serial data transfer with AcAS and logs the data daily. It allows channel-wise data plotting with dynamic X/Y-axis values and historian data plotting to visualize historical data trends. It also offers a live-sensor value graphical plot for real-time insights. The key modules include I/O_scan_task_Analog(Karagiozidis and Gergeleit 2023), which scans and processes analog I/O data, and I/O_scan_task_Digital (Lei et al. 2009). The

I/O_scan_task_Analog task samples data and switches the analog output value to four AO channels every 100 ms by using a semaphore to prevent memory corruption. The SBC maintains two tables for analog data updated every 100 ms. Other important modules include Debug_task (Zou et al. 2023) for debugging operations, WiFi_task(Gallemit and Andrew 2023) for WiFi connectivity tasks, DispTouch_task (Abinaya et al. 2019) for display and touch functionalities, and Extemem_task (Kameshwar et al. 2022) for external memory operations. The main function serves as the entry point for the program. Each module is represented in a block diagram and associated with specific source files.

# Environmental sensors

The ideal temperature for sustainable shrimp aquaculture is 28–30°C. The pH should be kept between 6.8 and 8.0 for effective ammonia-nitrate-nitrogen conversion in Biofloc (Pierri et al. 2015). An Industrial pH probe (KIT-102P) with an IXIAN-pH transmitter was used to monitor the pH of the pond water, which ranged from 0–14, with a resolution of ± 0.001 (Fig. 5). Probiotic bacteria in biofloc systems depend on suspended solids for adhesion and as carbon sources (Hlordzi et al. 2020). Oxidation−reduction Potential (ORP) sensors, which measure the oxidizing or reducing the tendency of pond water, should ideally register 650–700 mV for optimal shrimp production (VanDuc et al. 2018; Gao et al. 2019; Nair et al. 2020). An Industrial ORP probe (KIT-103O) with an IXIAN-ORP transmitter was employed to measure the ORP, which ranged from ± 2000 mV, with a resolution of ± 1 mV. A conductivity sensor measures the solution's ability to conduct an electrical current, which is directly proportional to the pond's metal ion concentrations, and should be maintained at 2.7 dS m − 1 (Kruse et al. 2020; Alarcón et al. 2021). An Industrial Conductivity probe (Kit-1.0) with an IXIAN-EC transmitter was used to determine the conductivity, ranging from 5 to 2, 00, 000 µS/cm, with a 2% resolution. To ensure that the system functions properly, given the oxygen demand of the algae and bacteria of the biofloc system, dissolved oxygen should be kept at 7–8 ppm (Nagothu 2021; Wang et al. 2022). An Industrial DO probe (KIT-106D) with an embedded circuit was used to detect DO, ranging from 0-100 mg/L, with a resolution of ± 0.05 mg/L. All probes had a 4-20mA data output and were operated at a voltage of 9-36V.

# Operation

AcAS, powered by a 12V, 2A DC supply, boots up to display a logo, followed by the 'Home Screen' after initialization (Fig. 6). This screen displays a menu for different pages and the current time and date, which can be updated via the setting page. The 'Home Screen' also features functional icons for easy navigation:

- 'Date and Time' icon: Displays the current date and time.
- 'Desktop' icon: Navigate to the 'Home Screen' page.
- 'Settings' icon: Leads to the Settings page for adjusting system settings.
- ’Wireless’ icon: Directs to the Wireless module on/off page to control the system's wireless modules.
- 'Status' icon: Navigate to the status page displaying the status of operations and sensors.

- 'Analytics’ icon: Leads to the Sensors Data’ Analytics’ page to view sensor data graphically.
- 'Manual' icon: Navigate to the Manual Operation page for manually controlling attached devices.

These icons provide easy access to various features and settings, thereby simplifying the configuration and management of the AcAS.

# Settings

The “Settings page” of the AcAS offers various buttons for accessing different settings and configurations:

- 'Change Date and Time' button: Adjusts the unit's date and time.
- 'Turn ON/OFF WIFI' button: Controls the WIFI module.
- 'Turn ON/OFF Zigbee' button: Controls the Zigbee module.
- 'Turn ON/OFF GSM' button: Controls the GSM module.
- 'Select GPRS Operator' button: Selects a GPRS operator for network communication.
- 'Add Control Loop' button: Adds a new control loop for Auto/Timer mode operation.
- 'Remove Control Loop' button: Removes a configured control loop.
- 'Auto Mode Status' button: Provides information about the control loop's current status.
- 'Manual Mode Status' button: Provides information about manual mode operation status.
- 'Edit Analog Sensor' button: Edits details of analog sensors.
- 'Edit Wireless Sensor' button: Edits details of wireless sensors.
- 'Sensor Statistics' button: Displays sensor data graphically.

These buttons simplify the configuration and management of the AcAS by providing easy access to various features and settings.

# Change date and time

The 'Date and Time Edit' page displays the current date and time and fields for entering new values for day, month, year, hour, minute, and second. These fields allow for adjustments to the module's date and time settings. These changes can be applied to update the internal clock of the system.

# Date and time configuration

To set the Date and Time, go to the respective page and input the desired value. Click 'Update Date' or 'Update Time' to apply changes. Optionally, use 'Sync Date & Time' to synchronize the microcontroller with the graphic LCD. Click 'Back' to return to the settings page. To control wireless modules, go to the settings page and click on the buttons for WIFI, LoRa, or GSM. This leads to the WIRELESS page, where these modules can be turned ON or OFF, as needed.

# Control loop configuration

Setting up the control loop is crucial for the AcAS configuration. Navigate to the settings page and click 'ADD CONTROL LOOP' to reach the control loop selection page. Select the desired control loop and proceed to the Auto/Timer Mode Selection page. For the Auto Mode, click 'Auto Mode' and select the analog input (sensor) on the 'SELECT IO PORTS FOR THE CONTROL LOOP' page. Multiple sensors were selected for averaging. On the Limit/Range Enter page, the control execution triggering point is selected and the upper and lower threshold values are entered. In addition, the maximum and minimum sensor values, sensor names, and SI units were specified. The sensor name and SI unit are optional and displayed on the status page. If a previously configured sensor is selected, its details are displayed and edited by checking the checkbox in the bottom-right corner. This allows the modification of previously entered values.

# Digital input configuration

After editing the analog sensor value, proceed to the 'SELECT IO PORTS FOR CONTROL LOOP page. Select 'Digital IN' to select a digital input channel. Multiple Digital IN input channels can be added to the control loop. If more than one digital input channel is selected, a logical operation window appears to apply the AND, OR, or XOR operations. Note: The twelfth digital input pin was reserved for internal purposes. Next, the Digital Output was configured by selecting the desired digital output and setting the ON state interval. Note: Up to five digital outputs can be assigned to one control loop. After configuration, the status is displayed on the 'SELECT IO PORTS FOR THE CONTROL LOOP' page. Channels can be deleted and reconfigured using the 'clear' button. On the Finish Control Loop setup page, choose 'Start Now' to initiate operation immediately, or 'Save Only' to save the configuration for later use. Note: The configuration process can be canceled at any time by clicking the 'Cancel' button.

# Timer mode

Navigate to the settings page and select 'Add Control Loop' to configure the AcAS in timer mode. Choose a control loop and proceed to the auto/timer mode-selection page. Here, select 'Timer Mode' and configure the analog and digital input channels. Subsequently, a Digital Output channel is selected and navigated to the Timer Configuration page. Set the start time and DO Open interval time for specific intervals or set the start time, Time Interval, and count value for multiple operations per day. If you need to remove a configured control loop, go to the Settings page, select 'Control Loop Status,' choose the control loop you want to Start/Stop/Remove and select the operation. To edit Analog IN sensor details, select 'Edit Analog Sensor' on the Settings page, choose the Analog IN channel to edit, and enter or edit details on the Analog Sensor Detail page. The system also supports wireless operations. There are buttons on the wireless page that allow control of the WIFI, GSM, and Zigbee modules. The Status page displays the status of manual operation, control loop, analog sensor values, and sensor data in a graphical format, providing a comprehensive overview of the system's operation.

# Manual mode

To access the Manual Status page of the AcAS, go to the status page and click on the Manual Status icon. This action directs you to the Manual Status page. If you want to go back to the previous page, just click on the 'Back' button located in the top-right corner of the Manual Status page. Manual operations in an Aquaculture Automation system are split into two windows. Click the 'Manual' icon on the bottom taskbar to access the first page of manual operation. The buttons on this page are only active if the rotating switch on the AcAS panel box is set to 'Manual.' The first window displays the first 12 sets of switches, and the remaining 12 sets are displayed in the second window. Navigate to the second page by clicking the corresponding button on the top-right corner of the first window. To return to the first page, click the 'back' button in the top-right corner of the second page. Note that manual operation of the switches is not possible if the system is in 'Auto' mode.

## Auto mode

To view the Auto Status page, navigate to the status page and select the 'Auto Status' button. All configured control loops were color-coded according to their status: green for running, purple for stopped, and gray for non-configured. A control loop is selected to view its status and configuration values. The Sensor Status page, which is accessible from the status icon on the bottom taskbar, displays the sensor name and the current value for each sensor. The Sensor Statistics page provides a graphical representation of sensor values, with buttons labeled 'SN 1–4,' 'SN 5–8,' and 'SN 9–12,' displaying graphical values for respective sensors. The graph represents the percentage versus time. This page is also accessible on the settings page. AcAS color codes all configured control loops based on their status: green for running, purple for stopped, and grey for non-configured. To start, stop, or remove a control loop, it is selected from the initial window. An orange selection circle appeared around the selected loop. Click 'Next' to proceed to the next page, where you'll see three options: 'Start Operation,' 'Stop Operation,' and 'Remote Operation.' Choose the desired action and click 'Finish.' The system saves a new configuration based on the memory selection.

## Field installation and performance evaluation

The AcAS System, designed for aquaculture farming, addresses the challenges in pond environments (Fig. 7). It operates based on test parameters stored in a medium attached to the unit, with control operations divided into modes that are selected automatically based on user inputs and measurements. The initial validation was conducted in a controlled laboratory environment using simulated sensor inputs integrated with relay modules. The system showed improvements in yield by optimally controlling water parameters. Automation of aquaculture farms is gaining traction in developing countries for sustainable and uniform shrimp growth. Field validation and fine-tuning were jointly conducted by the Centre for Development of Advanced Computing (Ministry of Electronics & Information Technology), Thiruvananthapuram, Kerala, India, Bharathidasan University, Tiruchirappalli-620024, Tamil Nadu, India. The system achieved TRL-7 and is ready for field deployment.

## Sustainability

AcAS is a comprehensive solution for aqua farming designed to monitor and control various parameters in the ecosystem using multiple sensors. It operates pumps and valves based on the collected data and pre-configured algorithms, making it adaptable to different fields in the sector (Fig. 8). The system features a user-friendly, customizable graphical interface, and uses efficient sensors for precise results, ensuring safe shrimp growth. It stores data on an attached memory device and has built-in communication modules for data transfer. Farmers can configure devices to receive alerts and remotely control field equipment. AcAS is designed for Indian farming scenarios and includes a wireless interface for data collection and remote control of equipment. It uses industrial-grade environmental sensors for precise results, even under harsh conditions, thereby reducing the need for frequent replacement. The data storage capability of the system eliminates the need for paper records and contributes to resource conservation. Its compatibility with modern communication technologies ensures its long-term viability. Farmer-friendly design promotes optimal shrimp growth conditions, leading to sustainable farming practices. By providing updates and alerts, AcAS enables proactive management of aquaculture, reducing potential environmental impacts. Thus, AcAS contributes to sustainable aquaculture through efficient resource use, waste reduction, and promotion of best practices.

## Conclusions

AcAS is a significant advancement in aquaculture farming, with potential for further development. The integration of advanced and diverse sensors could allow for the monitoring of additional environmental parameters, leading to more precise control of farming conditions. Improvements in data analysis and machine-learning algorithms could enable the system to predict environmental changes and proactively adjust farming practices. More robust and energy-efficient hardware can enhance the durability and longevity of a system, particularly under harsh conditions. The integration of renewable energy sources such as solar power could reduce the environmental impact of the system. The system can be customized for different types of aquaculture, broadening its applicability. However, challenges remain, such as harsh environmental conditions that affect sensor accuracy, technical issues in deploying sensor networks, and electricity scarcity with inadequate communication. High fish densities can lead to pollution and disease, thereby affecting product quality. Integrating advanced technologies into existing systems to enhance production and environmental friendliness is a significant challenge. Existing models work well in small settings; however, scalability for larger setups requires constant monitoring calls for big data and cloud computing-based systems. Despite these challenges, the user-friendly design, precise monitoring capabilities, and adaptability of AcAS make it a promising tool for the future of sustainable aquaculture.

## Declarations

# Conflict of interest

The authors declare that they have no conflict of interest.

# Author Contribution

Design, development, and deployment of a sensor-based aquaculture automation system Author contributionMr. R. Sasikumar : Data collection, Experiments Performing, and manuscript writingMs. L. Lourdu Lincy : Data collectionMr. Anish Sathyan : Research idea, conceptualization and work design Dr. P. Chellapandi : Conceived the research idea, work design and manuscript correction

# Acknowledgments

The authors express their gratitude to the Ministry of Electronics and Information Technology, Government of India (27(1)/2020-ESDA), for providing financial support.

## References

1. Abinaya M, Survenya S, Shalini R, Sharmila P, Baskaran J Design and implementation of aquaculture monitoring and controlling system. In2019 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC) 2019 Mar 27 (pp. 232–235). IEEE
2. Agustianto K, Kustiari T, Destarianto P, Wiryawan IG Development of realtime surface modeling vehicle for shrimp ponds (ReSMeV-SP). InIOP Conference Series: Earth and Environmental Science 2021 Mar 1 (Vol. 672, No. 1, p. 012088). IOP Publishing
3. Akram W, Casavola A, Kapetanović N, Miškovic N (2022) A visual servoing scheme for autonomous aquaculture net pens inspection using ROV. Sensors 22(9):3525
4. Alam TJ, Hayder AA, Apu AF, Banna MH, Rahman MS IoT Based Biofloc Aquaculture Monitoring System. InProceedings of the Fourth International Conference on Trends in Computational and Cognitive Engineering: TCCE 2022 2023 May 28 (pp. 99–112). Singapore: Springer Nature Singapore
5. Alarcón-Silvas SG, León-Cañedo JA, Fierro-Sañudo JF, Ramírez-Rochín J, Fregoso-López MG, Frías-Espericueta MG, Osuna-Martínez CC, Páez-Osuna F (2021) Water quality, water usage, nutrient use efficiency and growth of shrimp Litopenaeus vannamei in an integrated aquaponic system with basil Ocimum basilicum. Aquaculture 543:737023
6. Biazi V, Marques C (2023 Aug) Industry 4.0-based smart systems in aquaculture: a comprehensive review. Aquacult Eng 19:102360
7. Blancaflor E, Baccay M Design of a solar powered IoT (internet of things) remote water quality management system for a biofloc aquaculture technology. InProceedings of the 2021 3rd Blockchain and Internet of Things Conference 2021 Jul 8 (pp. 24–31)
8. Blancaflor EB, Baccay M (2022) Assessment of an automated IoT-biofloc water quality management system in the Litopenaeus vannamei’s mortality and growth rate. Automatika: časopis za automatiku, mjerenje, elektroniku, računarstvo i komunikacije. ; 63(2):259 – 74

9. Chellapandi P (2021) Development of top-dressing automation technology for sustainable shrimp aquaculture in India. Discover Sustain 2(1):26
10. Das BK, Meena DK, Das A, Sahoo AK Prospects of Smart Aquaculture in Indian Scenario: A New Horizon in the Management of Aquaculture Production Potential. InSmart and Sustainable Food Technologies 2022 May 14 (pp. 59–85). Singapore: Springer Nature Singapore
11. Ezhilazhahi AM, Bhuvaneswari PT IoT enabled plant soil moisture monitoring using wireless sensor networks. In2017 Third International Conference on Sensing, Signal Processing and Security (ICSSS) 2017 May 4 (pp. 345–349). IEEE
12. GALLEMIT ANDREWB (2023) Water Monitoring and Analysis System: Validating an IoT-Enabled Prototype towards Sustainable Aquaculture
13. Gao D, Liu M, Hou L, Derrick YFL, Wang W, Li X, Zeng A, Zheng Y, Han P, Yang Y, Yin G (2019) Efects of shrimp-aquaculture reclamation on sediment nitrate dissimilatory reduction processes in a coastal wetland of southeastern China. Environ Pollut 255:113219
14. Hlordzi V, Kuebutornye FKA, Afriyie G, Abarike ED, Lu Y, Chi S, Anokyewaa MA (2020) The use of Bacillus species in maintenance of water quality in aquaculture: a review. Aquacult Rep 18:100503
15. Huan J, Li H, Wu F, Cao W (2020) Design of water quality monitoring system for aquaculture ponds based on NB-IoT. Aquacult Eng 90:102088
16. Huang J, Kuang SR, Chang YN, Hung CC, Tsai CR, Feng KL (2019) AIoTs for smart shrimp farming. In2019 International SoC Design Conference (ISOCC). Oct 6 (pp. 17–18). IEEE
17. Jabeen T, Jabeen I, Ashraf H, Jhanjhi NZ, Yassine A, Hossain MS (2023) An Intelligent Healthcare System Using IoT in Wireless Sensor Network. Sensors 23(11):5055
18. Tang KS, Man KF, Chen G, Kwong S (2001) An optimal fuzzy PID controller, in IEEE Transactions on Industrial Electronics, vol. 48, no. 4, pp. 757–765, Aug. 10.1109/41.937407
19. Kameshwar Rao GV, Dhivya Shrilaa TJ, Akash I, Gugapriya G Aquaculture Monitoring System Using Internet of Things. InInternational Conference on Intelligent Cyber Physical Systems and Internet of Things 2022 Aug 11 (pp. 11–29). Cham: Springer International Publishing
20. Kanagachidambaresan GR IoT-Based Shrimp Farming. InInternet of Things Using Single Board Computers: Principles of IoT and Python Programming 2022 Dec 31 (pp. 265–279). Berkeley, CA: A
21. Karagiozidis A, Gergeleit M (2023) A Forensic I/O Recorder for Industrial Control Systems Using PLCs and OPC UA. InProceedings of the 18th International Conference on Availability, Reliability and Security. Aug 29 (pp. 1–9)
22. Kruse J, Koch M, Khoi CM, Braun G, Sebesvari Z, Amelung W (2020) Land use change from permanent rice to alternating rice-shrimp or permanent shrimp in the coastal Mekong Delta, Vietnam: changes in the nutrient status and binding forms. Sci Total Environ 703:134758
23. Lei Q, Shenfang Y, Qiang W, Yajie S, Weiwei Y (2009) Design and experiment of PZT network-based structural health monitoring scanning system. Chin J Aeronaut 22(5):505–512

24. Lindholm-Lehto P (2023) Water quality monitoring in recirculating aquaculture systems. Aquaculture Fish Fisheries 3(2):113–131
25. Nagothu SK Intelligent control of aerator and water pump in aquaculture using fuzzy logic. InMicroelectronic Devices, Circuits and Systems: Second International Conference, ICMDCS 2021, Vellore, India, February 11–13, 2021, Revised Selected Papers 2 2021 (pp. 160–171). Springer Singapore
26. Nair RR, Rangaswamy B, Sarojini BSI, Joseph V (2020) Anaerobic ammonia-oxidizing bacteria in tropical bioaugmented zero water exchange aquaculture ponds. Environ Sci Pollut Res Int 27:10541–10552
27. Pandey A, Andhale G, Sonawane A, Amrutkar A, Andhare T (2022) Automatic Water Level Indicator and Controller. Int J Res Appl Sci Eng Technol (IJRASET) 10(11):1043–1047
28. Pierri V, Valter-Severino D, Goulart-de-Oliveira K, Manoel-do-Espírito-Santo C, Nascimento-Vieira F, Quadros-Seifert W (2015) Cultivation ofmarine shrimp in biofoc technology (BFT) system under diferent water alkalinities. Braz J Biol 75:558–564
29. Rana SD, Rani S (2015) Fuzzy logic based control system for fresh water aquaculture: A MATLAB based simulation approach. Serbian J Electr Eng 12(2):171–182
30. Reis J, Weldon A, Ito P, Stites W, Rhodes M, Davis DA (2021) Automated feeding systems for shrimp: Effects of feeding schedules and passive feedback feeding systems. Aquaculture 541:736800
31. Haiyunnisa T, Alam HS, Salim TI (2017) Design and implementation of fuzzy logic control system for water quality control, 2017 2nd International Conference on Automation, Cognitive Science, Optics, Micro Electro-Mechanical System, and Information Technology (ICACOMIT), Jakarta, Indonesia, pp. 98–102
32. Towatana P, Voradaj C, Panapitukkul N (2002) Changes in soil properties of abandoned shrimp ponds in southern Thailand. Environ Monit Assess 74:45–65
33. Van Duc L, Song B, Ito H, Hama T, Otani M, Kawagoshi Y (2018) High growth potential and nitrogen removal performance of marine anammox bacteria in shrimp-aquaculture sediment. Chemosphere 196:69–77
34. Wang Q, Li S, Jia P, Qi C, Ding F (2013) A review of surface water quality models. The Scientific World Journal. ; 2013
35. Wang TW, Chang PH, Huang YS, Lin TS, Yang SD, Yeh SL, Tung CH, Kuo SR, Lai HT, Chen CC (2022) Effects of floating photovoltaic systems on water quality of aquaculture ponds. Aquac Res 53(4):1304–1315
36. Ye N, Long T, Shi R, Wu Y (2022) Radial basis function-assisted adaptive differential evolution using cooperative dual-phase sampling for high-dimensional expensive optimization problems. Struct Multidisciplinary Optim 65(9):241
37. Yu YB, Lee JH, Choi JH, Choi YJ, Jo AH, Choi CY, Kang JC, Kim JH (2023) The application and future of biofloc technology (BFT) in aquaculture industry: A review. J Environ Manage 342:118237

38. Zou X, Liu W, Huo Z, Wang S, Chen Z, Xin C, Bai Y, Liang Z, Gong Y, Qian Y, Shu L (2023) Current Status and Prospects of Research on Sensor Fault Diagnosis of Agricultural Internet of Things. Sensors 23(5):2528

# Figures

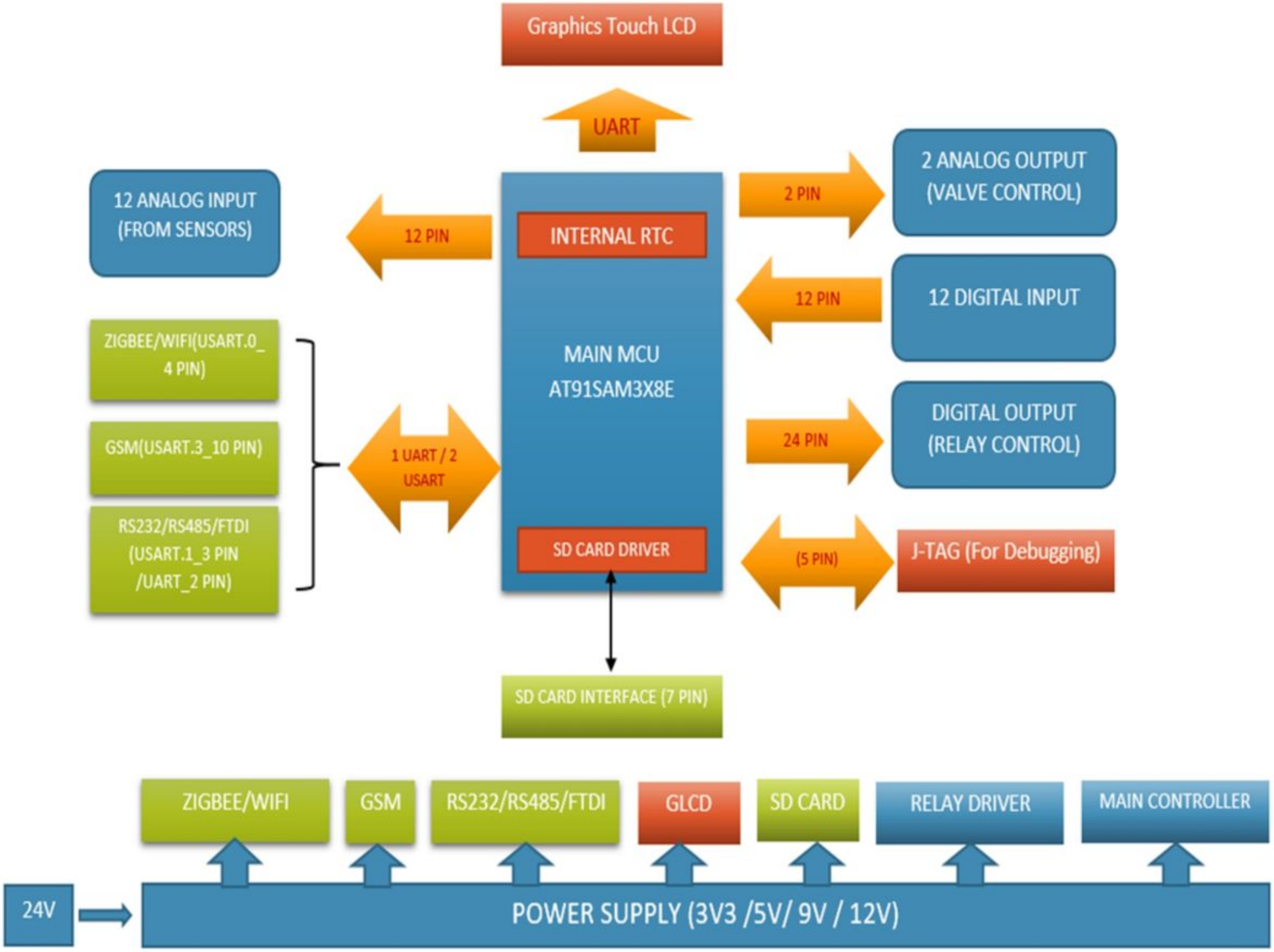


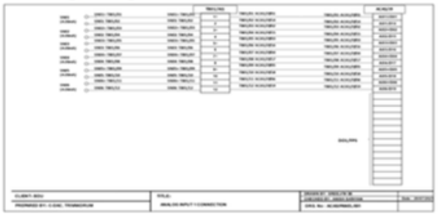
**Figure 1**

Systems design and architecture of AcAS and its modules

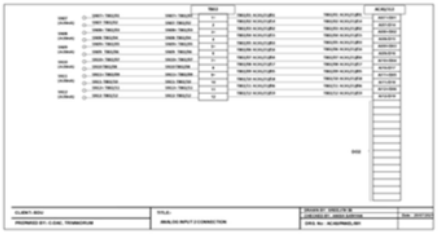
Analog Input Signals

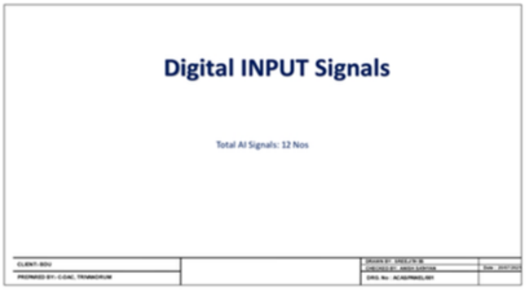
Total AI Signals: 12 Nos

Analogue input 1 connection



Analogue input 2 connection

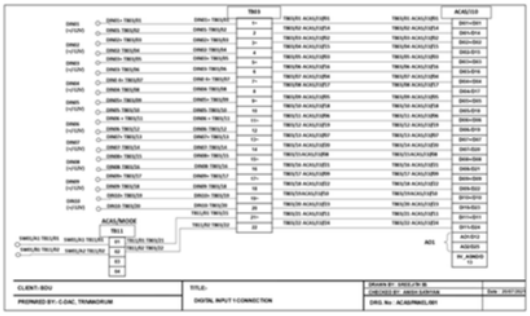


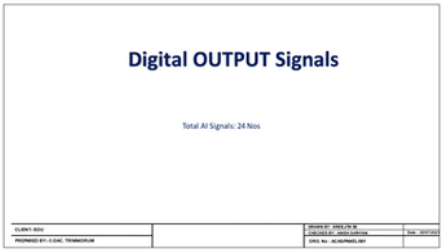


Digital INPUT Signals

Total AI Signals: 12 Nos

Digital input 1 connection

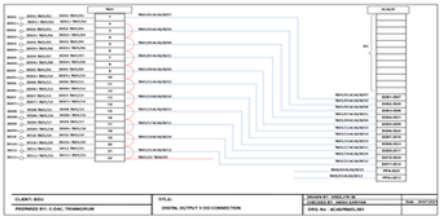




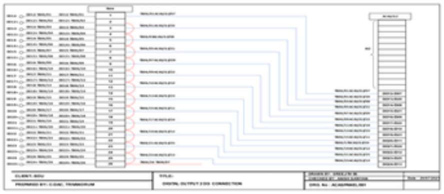
Digital OUTPUT Signals

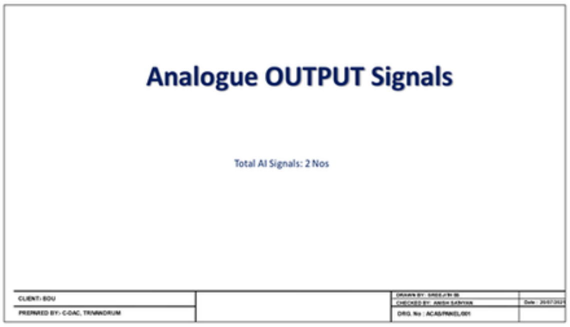
Total AI Signals: 24 Nos

Digital output 1/DO connection



Digital output 2/DO connection





Analogue OUTPUT Signals

Total AI Signals: 2 Nos

Analogue output connection

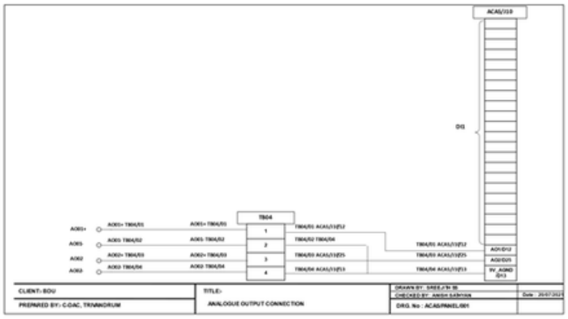
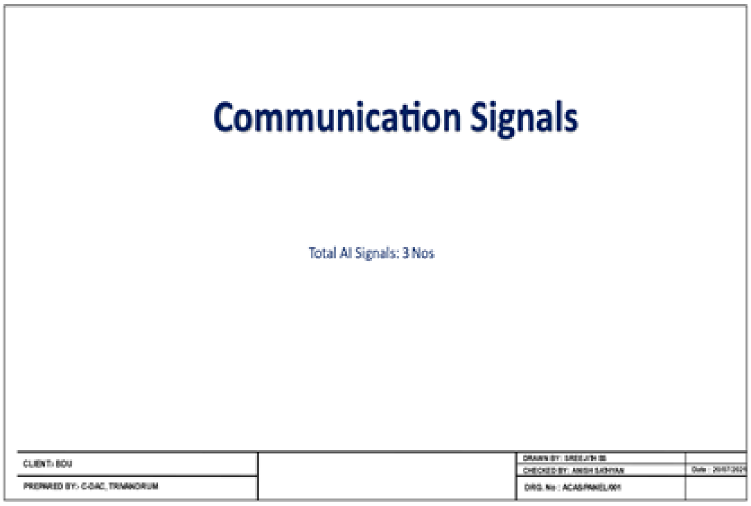


**Figure 2**

Analog and digital input and output signals and their configurations



## Communication Signals

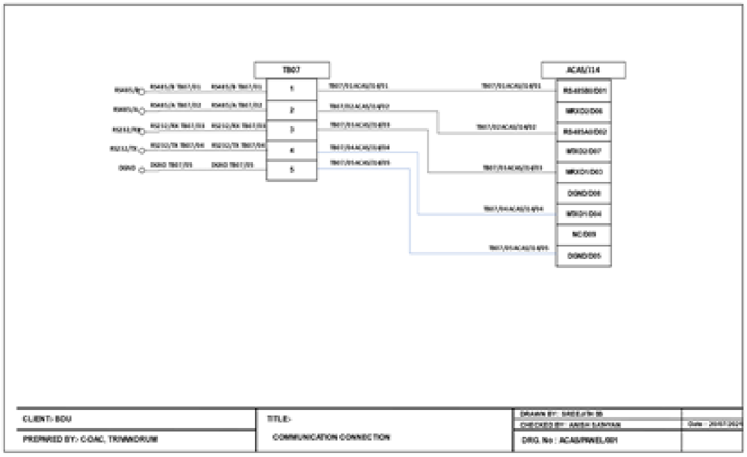
Total AI Signals: 3 Nos

CLIENT:- BDU

PREPARED BY:- C-DAC, TRIVANDRUM

DRG. No : ACAS/PANEL/001

Communication connection



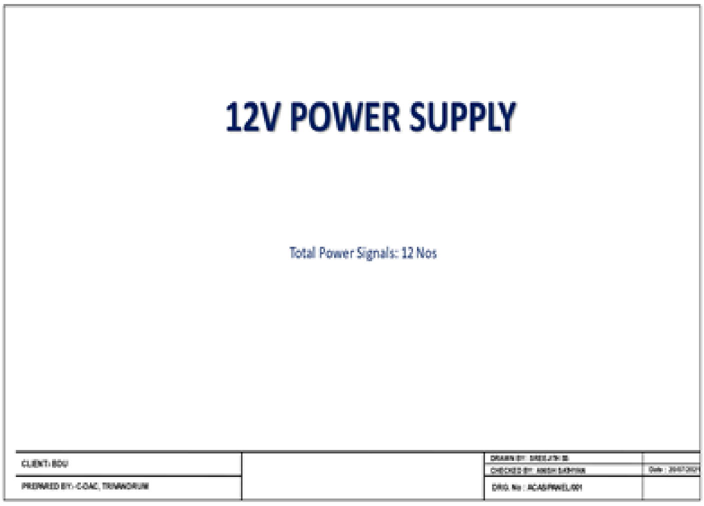
CLIENT:- BDU

PREPARED BY:- C-DAC, TRIVANDRUM

TITLE:-

COMMUNICATION CONNECTION

DRG. No : ACAS/PANEL/001



## 12V POWER SUPPLY

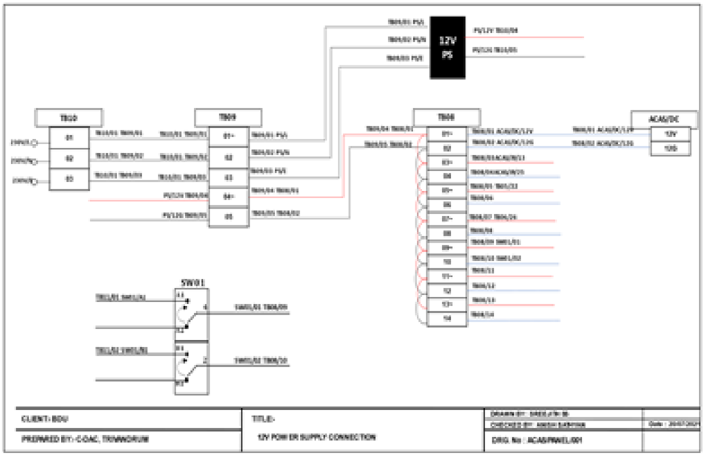
Total Power Signals: 12 Nos

CLIENT:- BDU

PREPARED BY:- C-DAC, TRIVANDRUM

DRG. No : ACAS/PANEL/001

12v power supply connection



CLIENT:- BDU

PREPARED BY:- C-DAC, TRIVANDRUM

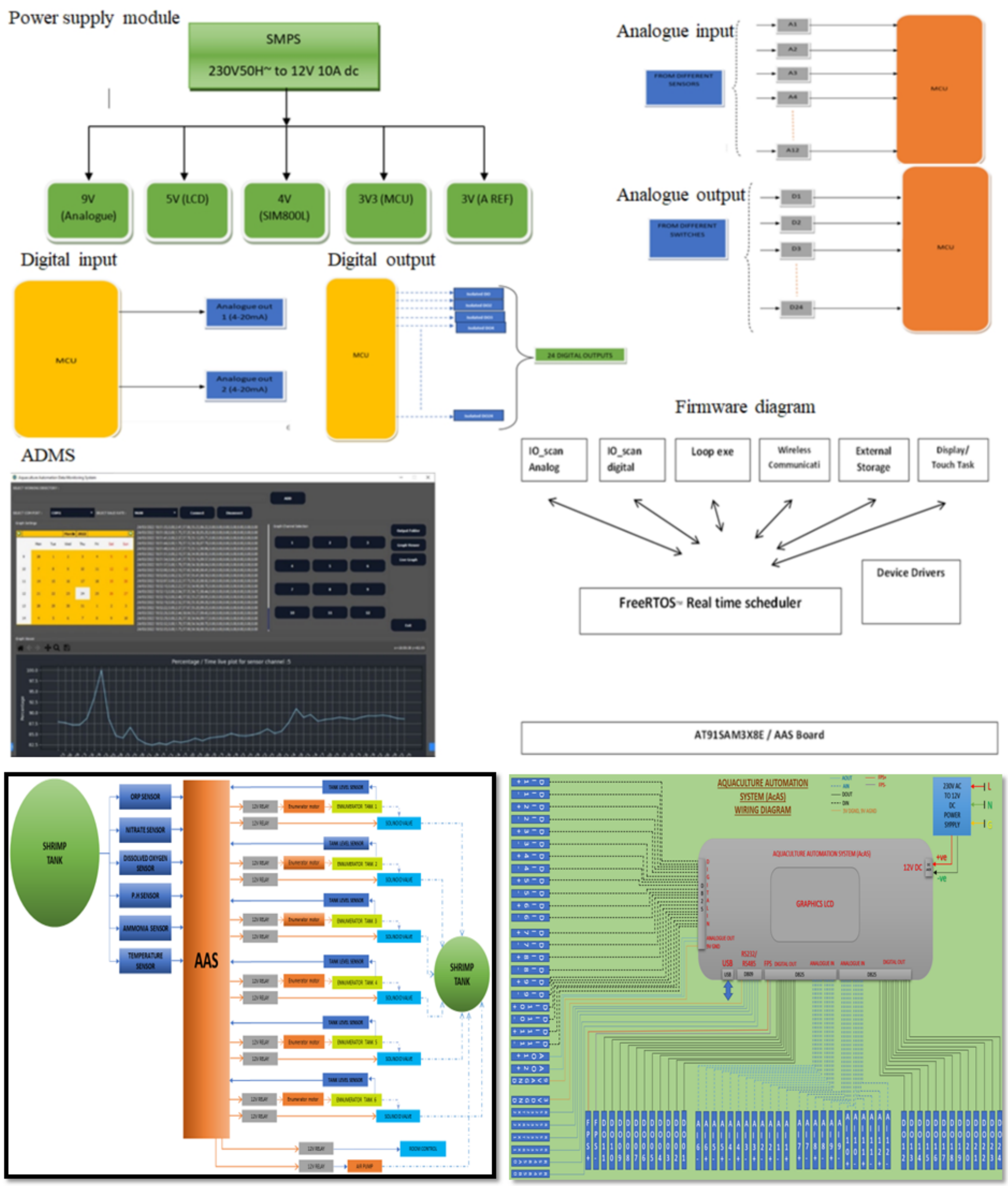
TITLE:-

12V POWER SUPPLY CONNECTION

DRG. No : ACAS/PANEL/001

**Figure 3**

Communication signals and their configurations



## Figure 4

Block-level design and its distributions

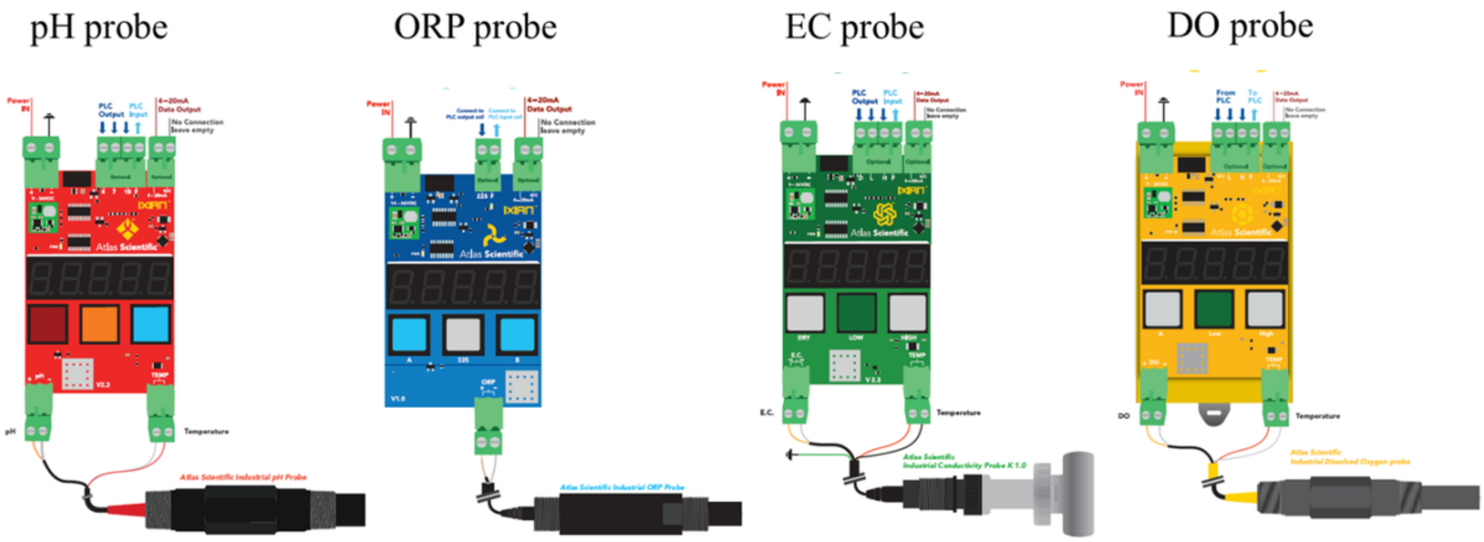
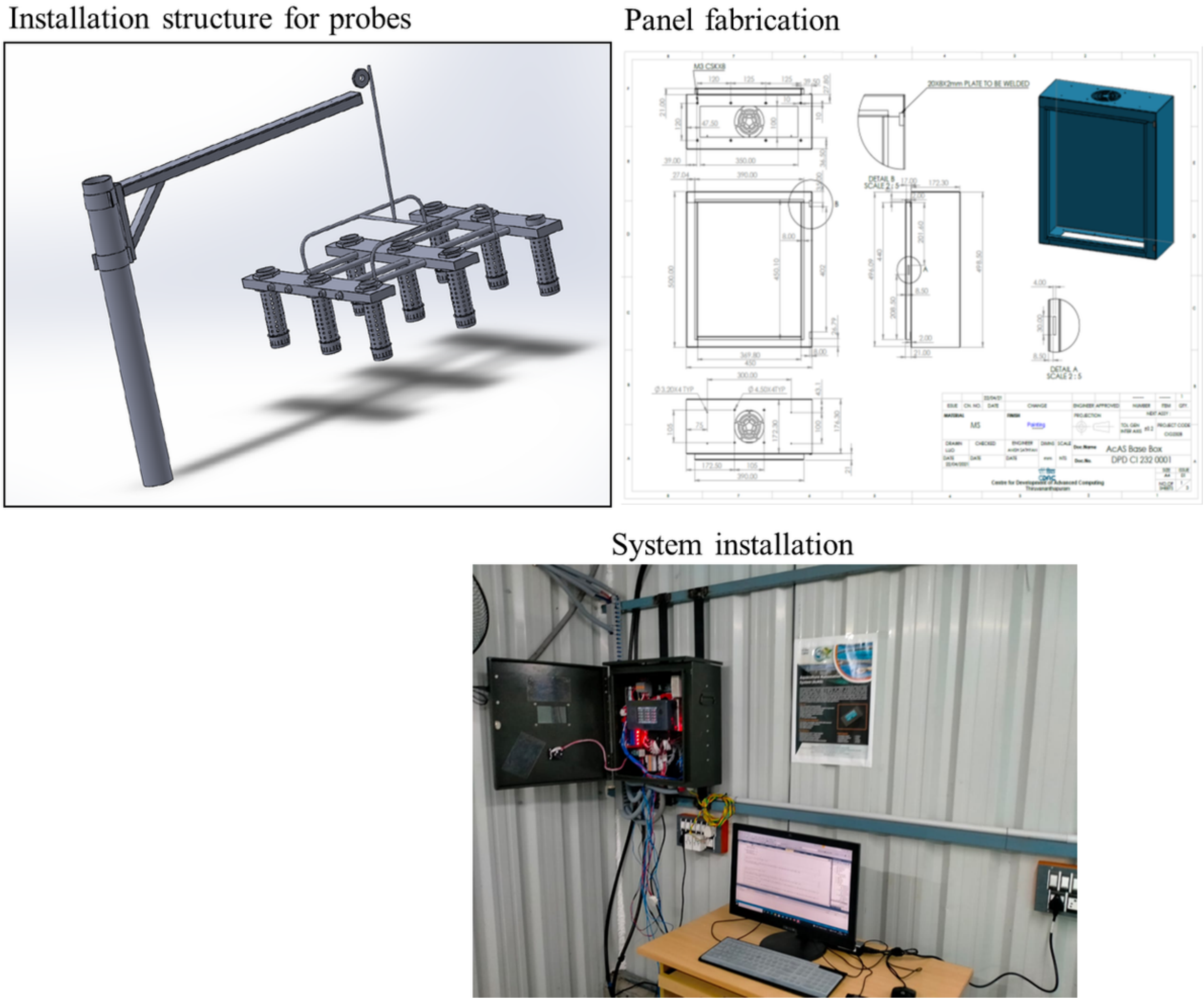


**Figure 5**

Industrial-grade probes used for online monitoring of pond water parameters

## Figure 6

Configuration settings and operation of AcAS



Installation structure for probes

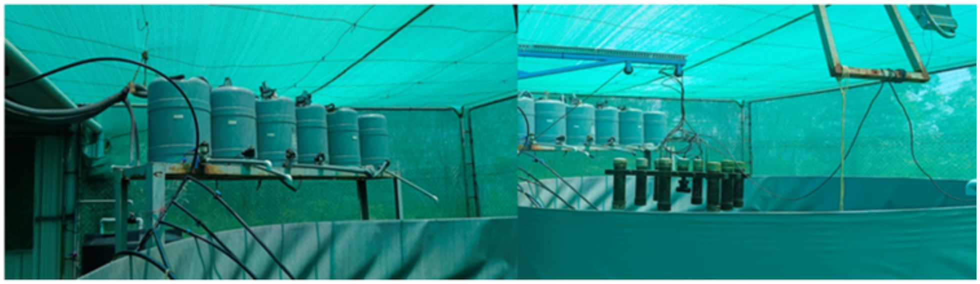
Panel fabrication

System installation

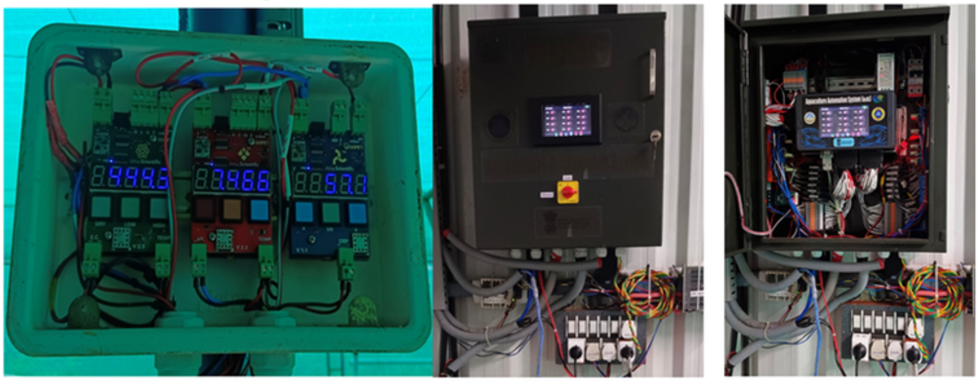
## Figure 7

Installation of probe cabinet and system in the field

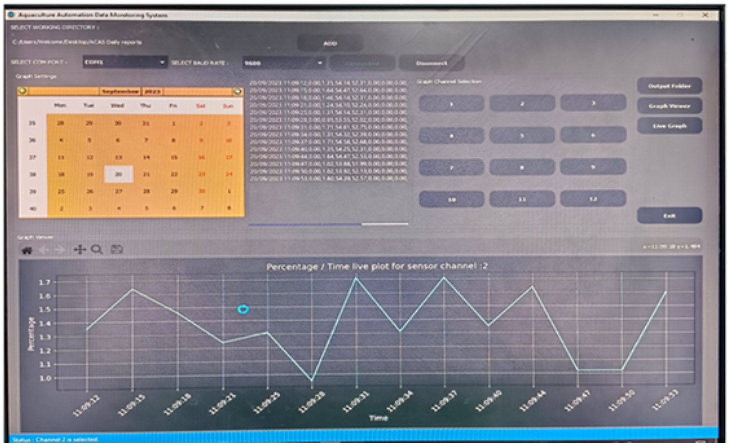
(A) Experimental site (B) Experimental pond view



(C) Top-dressing tank view (D) Probe cabinet view



(E) Sensor transmitter signals (F) Controller outer and inner view



(G) Graphical display view

## Figure 8

Deployment of AcAS in the shrimp aquaculture farm at Bharathidasan University, Tiruchirappalli, India