

IoT BASED WATER QUALITY MONITORING SYSTEM USING LORAWAN



SAVEL VA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR DEGREE OF MASTER OF ENGINEERING
PROGRAM IN ELECTRICAL ENGINEERING

FACULTY OF ENGINEERING

RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

ACADEMIC YEAR 2022

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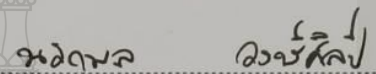


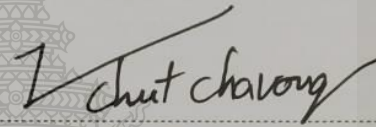
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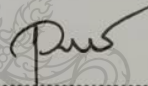
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Thesis Title IoT Based Water Quality Monitoring System Using LoRaWAN
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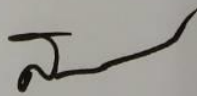

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ABSTRACTS

The thesis described IoT based water quality monitoring system using LoRaWAN applied by using a sensor to measure the values of water temperature, values of electrical conductivity, values of turbidity, quality values of dissolved oxygen, and values of pH can be applied by using the GPS that the system was confirmed with the water turbine of the sunshine and can exhibit the result and can collect the information throughout cloud computing system.

The water quality monitoring system was designed for working with solar cells and using the Arduino microcontroller in controlling work with transportation throughout architecture tool seller system of LoRaWAN by board CAT Starterkit Gravitech S76S which the average values information totally one kilometer that can collect information from quality of water through the system on the platform Cayenne Low Power Payload.

The results of experiments of water quality monitoring system on basic Internet of thing (IoT) showed that monitoring system can measure the temperature around 0-100 °C, electrical conductivity around 1-20 ms/cm, turbidity around 25-300 NTU, and dissolved oxygen in the water 4-12 mg/l, and pH values around 1-14 with the error value by a sensor measuring, as compared compare with standard tool is less than 5 %.

Keywords: water quality monitoring system, IoT, sensor, Arduino

หัวข้อขงวิทยานิพนธ์	ระบบตรวจวัดคุณภาพน้ำบนพื้นฐานไอโอทีโดยใช้ลอราแวน
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ปีการศึกษา	2565

บทคัดย่อ

วิทยานิพนธ์นี้นำเสนอระบบตรวจวัดคุณภาพน้ำบนพื้นฐานไอโอทีโดยใช้ลอราแวน โดยประยุกต์ใช้เซ็นเซอร์วัดค่าอุณหภูมิ ค่าการนำไฟฟ้า ค่าความขุ่น ค่าปริมาณออกซิเจนในน้ำ และค่า pH โดยสามารถระบุตำแหน่งด้วยระบบ GPS ซึ่งระบบได้ถูกติดตั้งร่วมกับกังหันน้ำพลังงานแสงอาทิตย์ โดยสามารถแสดงผลและจัดเก็บฐานข้อมูลผ่านระบบคลาวด์คอมพิวเตอร์

ระบบตรวจวัดคุณภาพน้ำถูกออกแบบให้ทำงานร่วมกับโซลาเซลล์ และใช้ไมโครคอนโทรลเลอร์ตระกูลอาดูโน ในการควบคุมการทำงานร่วมกับการส่งข้อมูลผ่านระบบสถาปัตยกรรมเครือข่ายแบบลอราแวนด้วยบอร์ด CAT Starterkit Gravitech S76S ซึ่งข้อมูลได้ในระยะทางเฉลี่ย 1 km โดยสามารถจัดเก็บข้อมูลคุณภาพน้ำผ่านระบบไอโอทีบนแพลตฟอร์ม Cayenne Low Power Payload

ผลการวัดทดสอบระบบตรวจวัดคุณภาพน้ำบนพื้นฐานไอโอที สามารถวัดค่าอุณหภูมิได้ในช่วง 0 – 100 °C วัดค่าการนำไฟฟ้าอยู่ในช่วง 1 – 20 ms/cm ค่าความขุ่นอยู่ในช่วง 25-300 NTU ค่าปริมาณออกซิเจนในน้ำอยู่ในช่วง 4-12 mg / l และค่า pH อยู่ในช่วง 1-14 โดยมีค่าความผิดพลาดของผลการวัดเมื่อเทียบกับอุปกรณ์มาตรฐานน้อยกว่า 5%

คำสำคัญ: ระบบตรวจวัดคุณภาพน้ำ ไอโอที เซ็นเซอร์ อาดูโน

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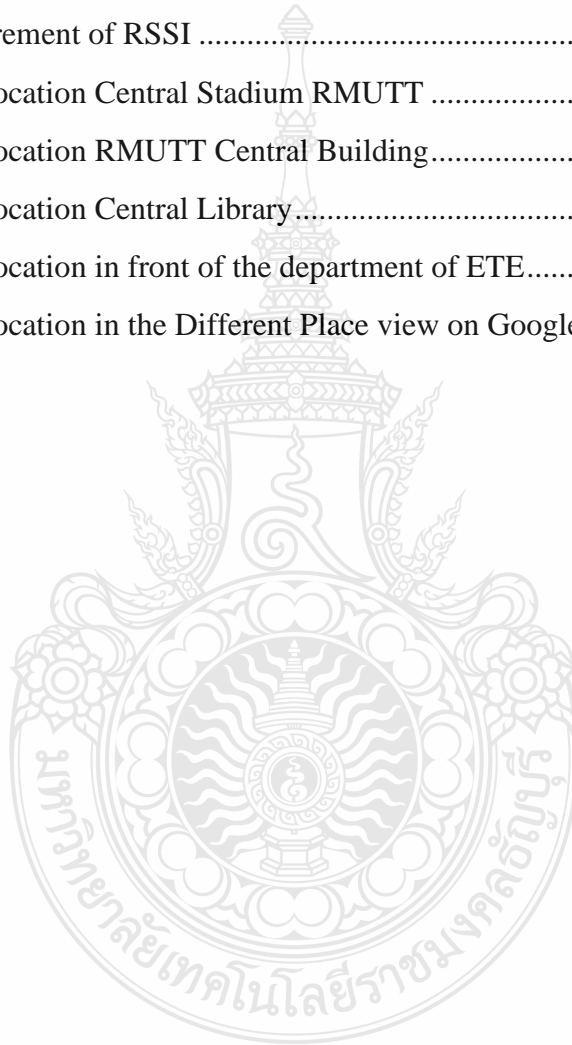
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List of Abbreviation

ABP	Activation by Personalization
BW	Bandwidth
CayenneLPP	Cayenne Low Power Payload (LPP)
Cloud	Cloud Computing
CSS	Chirp Spread Spectrum
EC	Electrical Conductivity
IDE	Integrated Development Environment
IoT	Internet of Things
GPS	Global Positioning System
GND	Ground
LoRaWAN	Long Rang Wide Area Network
LPWAN	Low Power Wide Area Network
NTU	Nephelometric Turbidity Unit
OTAA	Over the Air Activision
PCT	Patent Cooperation Treaty
pH	Potential of Hydrogen
SF	Spreading Factors
VCC	Voltage Current Circuit

CHAPTER 1

INTRODUCTION

1.1 Background Data and Problem Description

Nowadays, along with protecting water supplies from intentional or unintentional pollution, drinking water utilities, and consumer water supplies face new obstacles in the real-time process. Drinking water contamination is used as a transmission channel for a few dangerous substances that have negative effects on people and have major health consequences. As a result, better real-time in-pipe water quality monitoring systems must be installed at consumer locations as well as in the distribution mains. Monitoring the quality of drinking water in water distribution pipelines, lakes, rivers, and others is one of the uses for wireless sensor networks in smart cities that is crucial for human health [1]. The primary component of all life today is water which is required to sustain life [2]. According to research, the only reason why drinking tainted water causes 5 million deaths a year. By giving children access to drinking water, the World Health Organization's research indicates that about 1.4 million child deaths might be avoided [3]. Moreover, only 2.5 percent of this water is freshwater and even less than 0.3 percent of all freshwater is in rivers, lakes, and the atmosphere, which is critical to supporting life for people and every other living creature on the planet [4, 5]. All living things, including humans, depend on water as a natural resource [6]. Water is used by humans for a variety of purposes, including bathing, eating, washing, gardening, and raising animals. However, for some purposes, different measurements must be made in the water to make it suitable for usage. Despite being a necessity for life, living things still lack the water they need to survive. The primary cause of this severe water shortage is the poor quality of the water brought on by environmental damage. Water makes up upwards of 60 % of the human body, hence all living things must drink water. Water covers 71% [7] of the earth's surface and it is utilized for agriculture, manufacturing, swimming, drinking, and other recreational activities. It is challenging to determine the quality of water. The vast network of rivers, springs, wells, marshes, lakes, wetlands, estuaries, and bays that make up the world's water is covered in various levels of pollution. By the way, only 2% of the water on Earth is freshwater, even though it covers the majority of the planet's surface [8]. Due to problems depleting water supplies, an expanding population, and deteriorating infrastructure, utilities that provide drinking water face increasing difficulties in day-to-day operation [9, 10]. Fish is regarded as a low-cost source of proteins, which is crucial for lowering poverty, promoting health, and eliminating hunger. To build housing and increase the population, clean water sources are crucial [11]. Traditional methods for evaluating water quality involve the laboratory analysis of hand-collected water samples from various locations. These techniques give information about just the pharmacological, ecological, and physically properties of water, but they require a lot of work, are costly, and don't give meaningful data disconcerting water quality, which might be important in making solutions to ensure human safety [12]. Because present tactics are becoming less effective, it is necessary to create new strategies that make use of the internet-based tool to manage water quality. Water quality measurements are necessary to evaluate the mechanical, chemical, biologic, and microbial characteristics of the

substance. And the fact that a lot of chemicals used in daily life and industry eventually end up in water makes monitoring water quality extremely difficult. There are now not many clean water resources on the planet, and most water bodies are polluted. The health and survival of humans are profoundly impacted by water contamination. The world is experiencing issues with water demand and contamination because of growing globalization. The variables governing water quality and the hydrogen ion concentration are gauged by pH. It makes the water's alkalinity clear. The pH of pure water is 7, while the pH of acidic or alkaline water is higher than 7. pH values range from 0 to 14 and range of pH for drinking should be 6.5 to 8.5. The quantity of invisible suspended particles in water is measured by turbidity. The risk of diarrhea increases with turbidity. Turbidity levels below zero indicate pure water. A temperature sensor determines if the water is warm or cold. The water volume through with a flow sensor is measured. The manual collecting of water samples from various locations is a part of the conventional methods of water quality monitoring [13]. Water quality [14] is evaluated using physical, chemical, and biological markers. Electrical conductivity, turbidity, temperature, organic, total suspended particles, oxygen, and nutrient concentrations including both nitrogen and phosphorus are typical similar measurements for determining the extent of water contamination. Typically, sensors collect environmental data, which is then transformed into signals and stored in a data platform for later use.

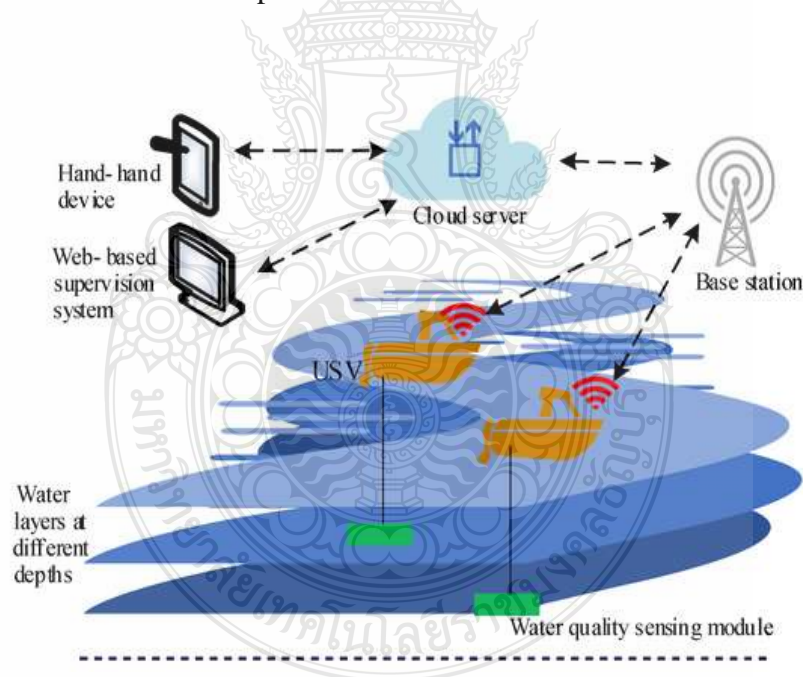


Figure 1.1 Water quality Monitoring System and Analysis [1]

The internet connects more than just people it also allows objects to converse with one another. Because it makes it so simple and quick for individuals to communicate with one another, the internet has become crucial to the global community. The term “Internet of Things” refers to the idea that items can communicate information over the

internet without needing to interact with other people or computers. Additionally, the Internet of Things is a technology of alliance with numerous objects and the capabilities of transmitting data through the system [3]. It is nothing more than a network of interconnected elements that serves as an illustration of the internet of things' revolutionary and growingly popular notion. The basic goal of the Internet of Things is to enable connections between any items and anyone or anything at any time, from any place, using any infrastructure or application [15]. Furthermore, Internet-of-things design makes it possible to leverage using cloud systems the trustworthy transmission, quick transmission, and huge transmitting data capacities, as well as intelligent systems, microcontrollers, wireless nodes, and gateways. The colony's water quality was monitored using internet of things architecture. Particularly, The IoT approach is mainly backed by hardware or microcontroller, such as the Raspberry Pi, Arduino, ESP8266, and others, that is used to operate sensor and actuators. These boards enable remote monitoring and control of sensor information through the internet [16].

The management and control of water quality utilities have seen significant advancement in internet-based technologies because so many monitoring devices need to be developed and calibrated over a big region, and such solutions are rather pricey. Especially, the utilization methodology for such techniques, in particular, needs to be suitable for a particular domain. Given the problems, the present employer has offered a low-cost internet of thing-based platform for controlling safe drinking water in live time. Furthermore, water tanks are still in operation in front of the department of Electronics and Telecommunication Engineering (ETE), and the absence of tank upkeep and clearing could result in dirty water. Moreover, there seems to be no system in place to stop water from becoming cloudy or to alert locals in advance of water issues. This motivated us to use the idea of the Internet of Things to send residents immediate notifications. The system's architecture makes it possible to detect the parameter of conductivity, temperature, turbidity, pH, and Global Positioning System (GPS) destinations values on the internet at the Rajamangala University of Technology Thanyaburi (RMUTT), Thailand. The sensors used are turbidity, Temperature (DS18B20), pH, and conductivity sensor connected with Board CAT Starter kit S767S, Arduino Nano attached with GPS. Additionally, tests are conducted on the capture, online data transfer, monitoring, recording, and evaluation of information on water management. Data from each sensor is connected to the system. Data collected from sensors and transmitted as well as through technology online services can be used to construct a system for monitoring groundwater resources.

1.2 Purpose of the Study

The objectives of this thesis are to generalize new concepts and to broaden the scope of prior works' notions. These new concepts include:

1.2.1 Study the microcontroller and sensor to measure the value of the potential of hydrogen, temperature, turbidity, conductivity, dissolved oxygen, and global positioning system (GPS).

1.2.2 Study of the LoRaWAN communication network.

1.2.3 Apply microcontroller and sensors with LoRaWAN communication system to design a water quality monitoring system using the LoRaWAN network.

1.3 Scope of Study

For this thesis, the following research areas and time constraints are related to earlier works:

1.3.1 Design and structure a water quality monitoring with LoRaWAN network and GPS Location.

1.3.2 The value of the potential of hydrogen, temperature, turbidity, conductivity, and dissolved oxygen can be transferred with a percentage of error less than 5%, and analysis parameters of the sensor can be applied in the water.

1.3.3 Water-based sensor specification the ambient conditions included a temperature range of 23 to 32 degrees Celsius, a pH range of 0 to 14, turbidity operating at 5v dc, producing voltage output ranging between 0.4 to 5 volts, the conductivity of 10,000 mhos/cm and the saturated dissolved oxygen in water at 25 to 32 degrees Celsius and parameter from 7.30 to 8.25 milligrams per liter (mg/L).

1.4 Contribution to Knowledge

The benefit of education and study in this subject of research is that we can build and improve our notions and knowledge around algebra and modules.

1.4.1 Microcontroller can be applied to transmit data over the LoRaWAN network for real-time display on cloud computing.

1.4.2 Provide information for those who are interested in using information such as applying in agriculture.

1.4.3 It can determine the location in real-time.

CHAPTER 2

LITERATURE OF STUDY

2.1 The construction of LPWAN

Low-Power Wide Area Network is a specialized broadband platform created for long-distance, small-bit-rate communications between IoT devices. IoT devices are directly connected to base stations in a star network architecture when using LPWAN. Like how the Wireless Fidelity (Wi-Fi) protocol and cellular networks are designed, LPWAN places a lot of attention on the network layer that is most closely related to how devices are physically connected and the medium access control layer while reducing the complexity of the upper levels (control layer and network layer). Wi-Fi offers wireless connections over a small distance of around 100 meters, but the cellular network offers connections over a vast area and at high throughput at the expense of significant energy and financial expenditure. The fact that LPWAN is distinguished from Wi-Fi and the cellular network by its long-range connection, low power consumption, cheap cost, low bit rate, and poor throughput is what differentiates LPWAN from those technologies. Therefore, the use of LPWAN is growing in remote control and monitoring systems that may span a city or a rural region and do not require significant volumes of data to be sent from the devices to the gateway [17].

There have been several LPWAN standards and protocols proposed for the Internet of Things, which may be further separated into licensed spectrum-based protocols and unlicensed spectrum-based protocols. There have been several LPWAN standards and protocols proposed for the Internet of Things, which may be further separated into licensed spectrum-based and unlicensed spectrum-based protocols. Operating in the unapproved sub-one gigahertz (GHz) Industrial, Scientific (ISM), and medical spectrum are protocols like Sigfox and LoRa/LoRaWAN. Unlicensed spectrum can be used for nothing. Unlicensed spectrum-based protocols must go by duty cycle limitations since many radio devices are using unlicensed spectrum and the resources are limited. This implies that no radio device can utilize the spectrum for more than $x\%$ of the time (x is determined by local regulations). The Third Generation Partnership Project standards, such as NB-IoT, constitute the foundation for the protocols that utilize the licensed spectrum. Government approval is required for the use of unregistered spectrum, and that raises the cost. However, protocols based on licensed frequency offer superior services and are exempt from duty cycle restrictions.

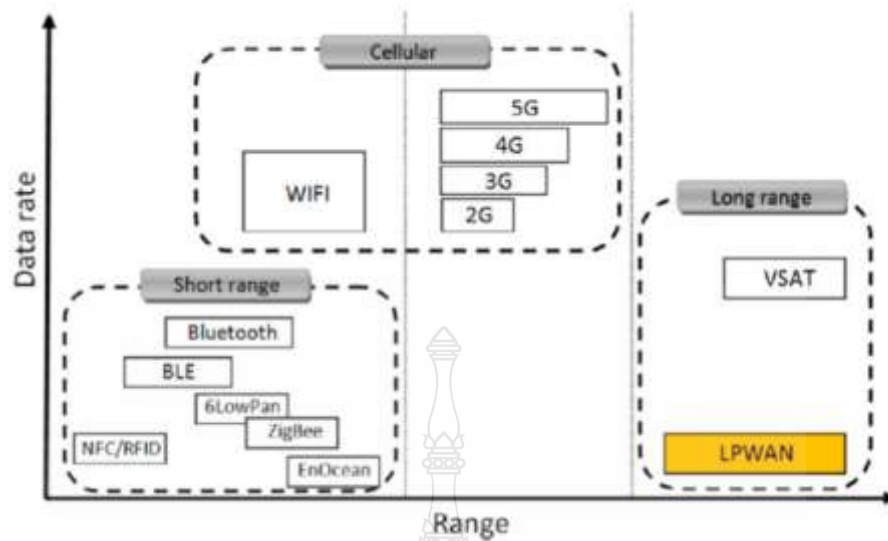


Figure 2.1 Technologies for LPW Communications [18]

2.1.1 Sigfox

It is shown as having the fewest number of uplink and downlink messages (140 each day) and the slowest transmission speed (100 bps). Up to 12 bytes of payload and up to 8 bytes of download are allowed for messages when they are being uploaded. Additionally, the cost of using the network per device is comparable to that of using the GPRS network in M2M (Machine to Machine) mode. Despite these drawbacks, SIGFOX is seen as a viable choice for a variety of agricultural applications because it doesn't require the deployment of any extra infrastructure and has a high coverage in several EU nations [18].

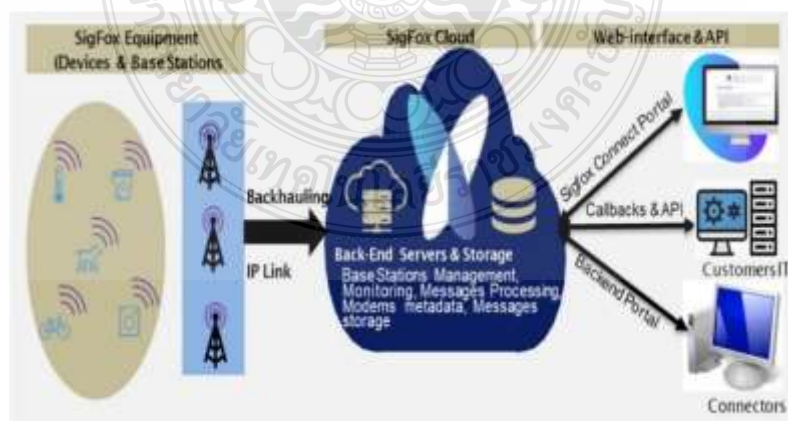


Figure 2.2 Sigfox flat architecture [19]

2.1.2 NB-IoT

To achieve high performance, NB-IoT is a 3GPP or 4GPP narrowband LPWAN technology that may work in conjunction with LTE or GSM within permitted frequency bands. The narrowband internet of things has a repetition bandwidth of 200 kHz for both uplink and downlink communication, and its strategy is founded on a communication protocol (LTE). As a result, some of the fundamental ideas and structural components of LTE are reprocessed in the physical and upper protocol layers of NB-IoT. In LTE M, the device utilizes the complete leveraging capacity of the wideband LTE carrier by receiving a portion of the LTE message as well as devices that are shared among multiple across the LTE carrier. NB-IoT devices, as opposed to Cat M1 devices, have the following characteristics: an NB-IoT carrier is present; all NB-IoT devices are given shared capacity, and the capacity may be extended by installing additional NB-IoT operators [19].

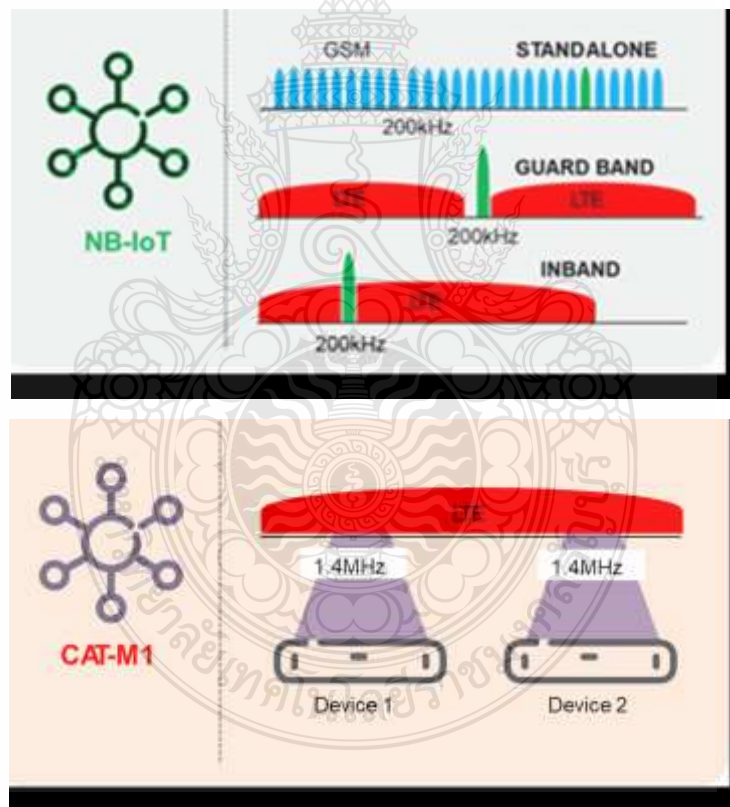


Figure 2.3 NB-IoT and Cat-M1 operational modes [19]

2.1.3 LoRa/LoRaWAN

Is open-source technology with a low-cost, autonomous, and independent private network setup capability. Compared to Sigfox and NB-IoT, LoRaWAN makes it possible to build network infrastructure and integrate them easily with a range of global network platforms. The research community has been interested in LoRaWAN virtually since the moment it hit the market because of its open-access specifications. Although there are other LPWAN family technologies, this article primarily focuses on the most current suggestions for how to advance LoRa/LoRaWAN technology. LoRa has been chosen as the LPWAN technology, based on its commercial penetration and the vast array of uses it has in the business, academia, and communities. A physical layer called LoRa uses low-energy, long-range radio technologies that operate in unauthorized radio channels at comment section levels. The LoRa WAN is The LoRa Alliance [20] and has supported and developed as a standard the medium connect directly authority protocol for moreover datalink zone and network layer of LoRa [19].

(Table 2.1) below are compiled all the details about the various LPWAN technologies discussed above, comparing a style of wireless communication that was created to offer connection for devices like remote sensors, actuators, and other machine-to-machine (M2M) and IoT devices. It has the characteristics of cellular technology, including extended range, low power electronics, minimal data rates, LoRaWAN, long-range (LoRa), and NB-IoT in terms of the spectrum they utilize, the maximum data rate per terminal, latency, modulation, whether they adhere to duty cycle regulations, the type of adaptation they employ, the MAC layer, and coverage range.

Table 2.1 LPWAN technology comparison of many methods [21]

	Sigfox	LoRa/LoRaWAN	NB-IoT
Spectrum	ISM (868-902MHz)	ISM (868-912-935mHz)	Licensed LTE and GSM
Data Rate	100bps-500bps	50kbps	50-60 kbps
Modulation	Ultra-Narrowband	Chirp Spread Spectrum	SC-FDMA/OFDM
Range	20–50 kilometers 3-10 kilometers	10–15 kilometers 2-5 kilometers	35 kilometers

2.2 LoRa

The chirp spread spectrum-based modulation known as LoRa was created by Cycleo in 2009 and purchased by SimTech in 2012. The similar frequency and timing differences throughout each of the receivers and the transmitter help to reduce the difficulty of LoRa modulation. The chirp signal, whose frequency fluctuates over time, is modulated with the data stream. The chirp rate determines a LoRa signal's spectral bandwidth (BW). For instance, a rate of chip 125000 chips/sec directly correlates to a spectral BW around 125 kHz. If we assume a given bandwidth, the data speed can vary depending on the spreading factor used. When represented as SF, the number of raw bits

conveyed by each symbol ranges from 7 to 12 [22]. The Forward Error Correction technique as in LoRa modulation adds redundancy to the code to detect and repair incorrect bits.

2.2.1 Chirp Spread Spectrum (CSS)

In contrast to older radio systems, which apply frequency-shift keying modulation to build connections, LoRa uses the chirp spread spectrum stimulation [23]. CSS is a modulation method used in digital communication that turns information into chirps or symbols whose frequency varies linearly over time [24]. Each symbol carries a different amount of data or bitrate depending on a crucial aspect called the spreading factor (SF). With a spreading factor of 7, for example, each symbol may transmit 7 bits while using LoRa, which uses an SF of up to 12. The CSS approach uses the complete allotted spectrum to transmit data. For years, CSS has only been used in paramilitary and storage tools owing to its low power and vast transmission lengths, but LoRa is the first limited deployment for civilian usage. Each chirp sweeps between the highest and lowest frequencies.

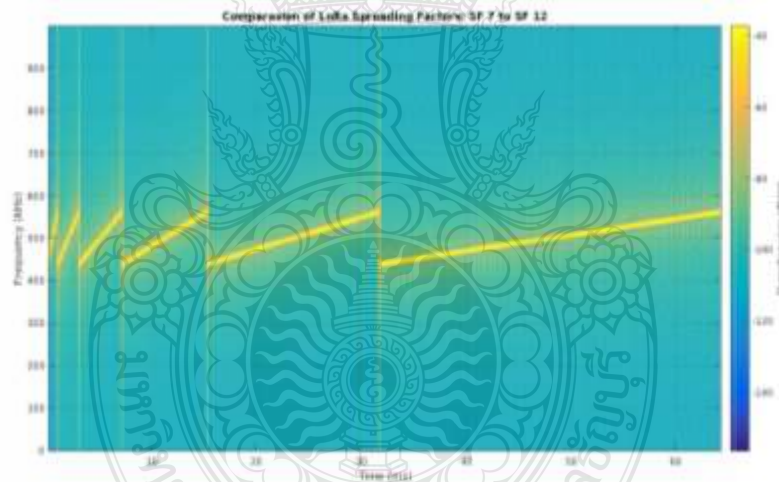


Figure 2.4 The LoRa protocol employs chirp spread spectrum modulation [25]

2.2.2 Spreading Factor

The spreading factor is one of several factors that affect a LoRa modulation's performance and range (SF). SF, which can take values between 7 and 12, specifies the maximum number of bits that a symbol may encode. SF directly affects the transmission time, which means that doubles the airtime by increasing it by one bit. On the other hand, a signal will receive better on the receiver side the longer it takes [26]. Therefore, a larger SF will result in a decrease in data rate and battery life.

Table 2.2 Spreading factor range [27]

(SF) (RegModulationcfg)	(SF) (Chips and symbol)	SNR for LoRa Demodulator (dB)
6	64	-5
7	128	-7.5
8	256	-10
9	512	-12.5
10	1024	-15
11	2048	-17.5
12	4096	-20

2.2.3 Bandwidth

Forward error correction is a data correcting technology that Semtech has used to provide a more dependable data delivery (FEC). In this type of coding method, extra bits are added to the transmission to aid in data recovery at the receiving end. The coding rates the proportion of redundant to non-redundant bits, and it is determined by [28]. For example, a data transfer with SF = 8 and CR = 4/8 indicates that twice as many real information-containment bits would be delivered.

$$CR = \frac{4}{4 + n} \quad (2.1)$$

2.2.4 Transmission Power

The amount of power required for a data packet to be transmitted can be adjusted as necessary in LoRaWAN networks. The battery can be preserved by reducing transmission power, although doing so would reduce the signal's range. Steps of 1 dB from -4 dBm to 20 dBm, the LoRa radio's TP may be adjusted. But because of hardware restrictions, TP ranges in real-world installations are typically restricted to 2 dBm to 20 dBm. Furthermore, only a duty cycle of 1% may be used if the TP levels are above 17 dBm [29].

2.2.5 Coding Rate

The equation for $CR = \frac{4}{4+n}$, where n ranges from 1 to 4. It means that five, six, seven, or eight transmission bits are used to encode every four usable bits. The amount of duration of the broadcast needed to communicate data increases as the coding rate decreases. By accounting for these characteristics, the nominal bit rate is determined. An equation has an equation for the bitrate [30, 31].

$$R_{bit} = SF \cdot \frac{BW}{2^{SF}} \cdot CR \quad (2.2)$$

2.2.6 Lora Packet Structure

Each packet delivered by a physical LoRa device has a structure that includes both necessary and optional components. There are two packet modes: explicit and implicit. No of the packet mode, a message always begins with a customizable number of up chirps as a prologue, followed by two down chirps. The synchronization between the receiver and the incoming message is also taken into consideration in the preamble. The header comes next and is only utilized in explicit mode. It includes the payload size, the coding rate (CR), and whether a 2-byte long cyclic redundancy check (CRC) is included. Contrarily, the implicit header mode employs fixed values rather than settable parameters, which shortens the transmission time [32].

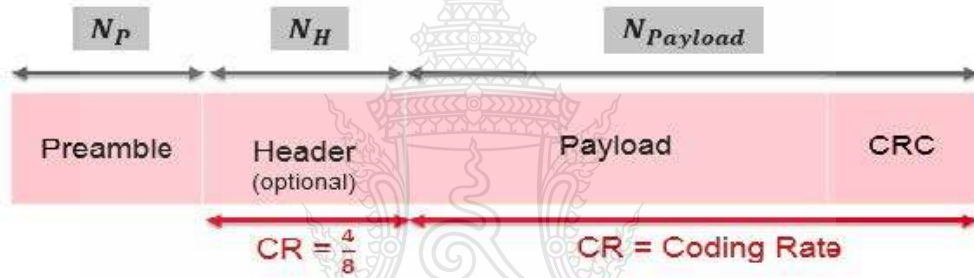


Figure 2.5 LoRa Packet Structure [30]

We begin by calculating the payload symbol before calculating the time on air. The equation may be utilized to determine the several symbols $N_{Payload}$ necessary to focus on providing a payload given PL, a spreading factor, and a coding rate [30].

$$N_{Payload} = 8 + \max \left(\text{ceil} \left(\frac{\Theta(PL, SF)}{\Gamma(SF)} \right) \cdot \frac{1}{CR}, 0 \right) \quad (2.3)$$

When $DE=0$, the low rate of data improvement is disabled and $H=0$, low data rate optimization is switched on. $\text{Ceil}(PL, SF) = 8 \cdot PL - 4 \cdot SF + 16 + 28 - 20 \cdot H$ is how the ceiling function is defined. Combining the durations of the preamble and payload, the equation determines the time on air [30].

$$T_{Packet} = T_{Preamble} + T_{Payload} \quad (2.4)$$

Where T_{Packet} , T_{Preamble} , and T_{Payload} stand for the duration of that and the packet, preamble, and payload, respectively. The preamble length is written as Equations [30].

$$T_{\text{Preamble}} = (4.25 + N_p) \cdot T_{\text{Symbol}} \quad (2.5)$$

Where T_{Symbol} denotes the preamble symbol period and N_p denotes the preamble symbol number. The time needed to send 2^{SF} chips is how it is defined. After then, remembering the chip rate and bandwidth BW are equal, the equation provides the symbol period Equation [30].

$$T_{\text{Symbol}} = \frac{2^{SF}}{BW} \quad (2.6)$$

The equation defines the payload duration [30].

$$T_{\text{Payload}} = N_{\text{Payload}} \cdot T_{\text{Symbol}} \quad (2.7)$$

2.3 Long Rang Wide Area Network (LoRaWAN)

The LoRa Alliance originally released the LoRaWAN certificate in 2015. LoRaWAN describes the LoRa MAC layer, which is known for its insufficient power consumption, network capacity, quality of service, and security [25]. LoRaWAN operates in an illegal sub-gigahertz industrial, scientific, and medical (ISM) band (around 863 to 870 bands in Europe and 902 to 928 megahertz in the United States of America). It transmits payloads of up to 250 Bytes across 5 to 15 kilometers (km) using the 125 kHz, 250, and 500 kHz bandwidths. The LoRa Alliance originally released the LoRaWAN standard in 2015. LoRaWAN is designed to maximize LPWAN deployment costs, capacity, range, and battery lifetime. The join procedure and message authentication are two essential security components of the LoRaWAN network. This ensures that only valid and verified end nodes are connected to genuine networks. Point encryption is a further security measure provided by LoRaWAN for application payloads exchanged between end nodes and application programming interfaces. LoRaWAN is one of just a few IoT systems that uses end-to-end encryption. LoRaWAN supports two types of end device activation: over-the-air and activation by personalization [29]. To clarify the relationship between LoRa and LoRaWAN, the well-known Open Systems Interconnection [33] paradigm is used. This model theoretically defines the communication of different systems with one another to facilitate system interoperability. The model defines seven levels with restricted duties and network protocol interfaces. Each layer may be swapped out. Lora corresponds to layer one of the OSI network

paradigm, meaning the physical layer [34]. LoRa can only send binary data. The ISM frequency band is used for this communication. The bits are modulated with the CSS method discussed above before being sent. LoRaWAN corresponds to OSI layers two (data connection) and three (network). LoRaWAN network layer role is primarily to relay packets via gateways; hence, this layer is sometimes overlooked in protocol stack explanations. LoRaWAN defines device classes, message formats, and various network administration instructions. MAC commands are transferred from the edge nodes to the domain controller or vice versa. The application server cannot see them. They are used to validate connectivity, adjust the data rate, configure the duty cycle and reception windows, and so on. The LoRaWAN stack is displayed. The physical layer with distinct frequencies at the bottom is laying the groundwork for communication. The LoRa modulation using CSS technology is the next component of this layer. The LoRaWAN MAC layer has been established on top of LoRa. There are three different device classes as well as MAC possibilities. The application layer is built on top of LoRaWAN. There, LoRaWAN frames are further processed.

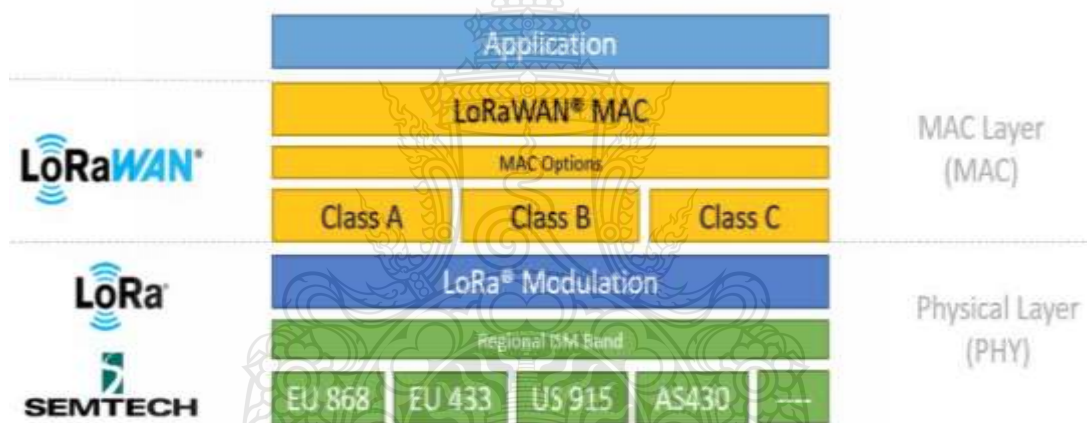


Figure 2.6 Protocol Stack for LoRaWAN [34]

2.3.1 Architecture of the LoRaWAN Network

The LoRa Alliance creates and maintains LoRaWAN, a networking protocol for the MAC layer that uses a LoRa physical layer to explore the upper layers of lengthy wide-area networks. All asynchronous nodes in the network, which transmit data when it is needed, have their data rates, communication frequencies, and transmission power maintained by LoRaWAN. The repeated packets will be filtered by the computer system, which also manages the network and offers data security. Any of the integrations that are offered delivers the received data to the application servers. Following are the three fundamental types of devices that a LoRaWAN technology architecture defines [19].

End Device: These are the accessories that either originate uplink data packets for transmission to gateways or accept downlink traffic from network servers.

Gateways: These are the devices that demodulate LoRa communications and transmit them between a wireless network's server and endpoints. Gateways are connected to the Internet through access points, which can be wired or wireless. The LoRaWAN gateway is clever; it can simultaneously provide thousands of ENs while listening to the radio on many channels.

Network Server: This is the device that acts as the LoRaWAN network's fundamental backend, gathering traffic from all end devices and processing it on an application server.

Application Services: Data from a sensor for detection are handled, managed, and safely analyzed by application servers. For connected end devices, they also create all application-layer downlink payloads [35].

Join Server: The information necessary to process uplink join-request frames and create a downlink join-accept framework is stored on connecting server [35]. It produces network and application session encryption keys and notifies the computer system which application server should be connected to the end device. The Application Activity Key is sent to the appropriate operating system server, and the Network Session Key is sent to the network server.

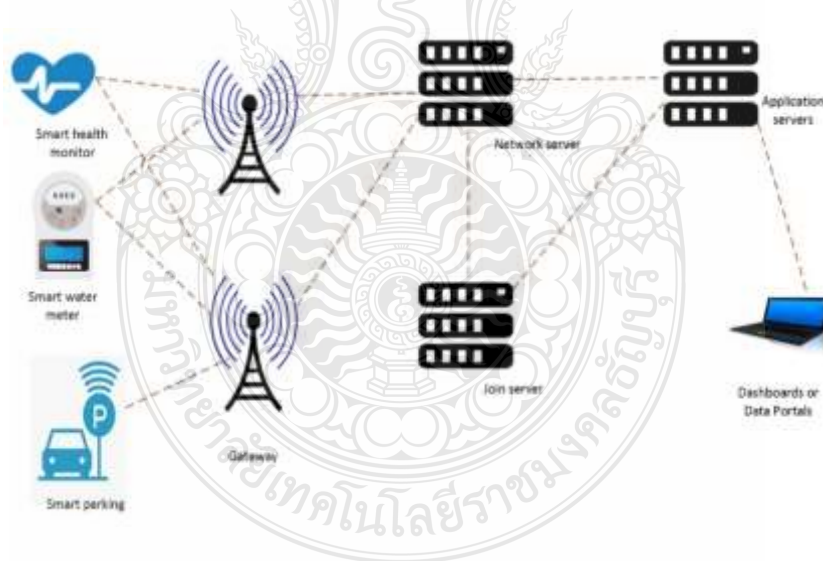


Figure 2.7 LoRaWAN Architecture [29]

2.3.2 LoRaWAN Class

LoRaWAN classifies operating modes as (A), (B), and (C) so on. All nodes must be initialized with class A, as the default mode is used when Ehlers-Danlos

syndromes (Eds) submit data to the GW using the ALOHA-based LoRaWAN Medium Access Control (MAC) protocol at any time [19].

Class A: Following each UL transmission, this class employs two receiving windows. Only DL broadcasts are permitted at the start of these reception periods. Regarding the first window, DL transmissions utilize the same bandwidth efficiency and channel parameters as the preceding UL transmission. Nonetheless, the second window operates at 869.525 MHz with a static configuration (SF12/125 kHz).

Class B: As confirmation that using this mode is desired, the base station is required to provide extra information for ED to operate in this optional option. Even though there has been no previous broadcast from the EN, the GWs open new reception windows by emitting synchronization beacons. Class B allows for a greater number of receiving windows than Class A, but at higher energy usage. Following each UL transfer, the additional regular receiving windows are opened, in addition to the synchronized opening of the two normal receiving windows, known as ping slots. To ensure synchronization, GW beacons are broadcast every 128 seconds. The useable beacon window is the time interval between two beacons.

Class C: The endpoints always keep their reception windows open they only close themselves when the UL forwards a packet to one of them. Because Class C requires devices to receive continually, which is incompatible with Class B, these ENs increase power consumption. Class B is not supported by Class C hardware.

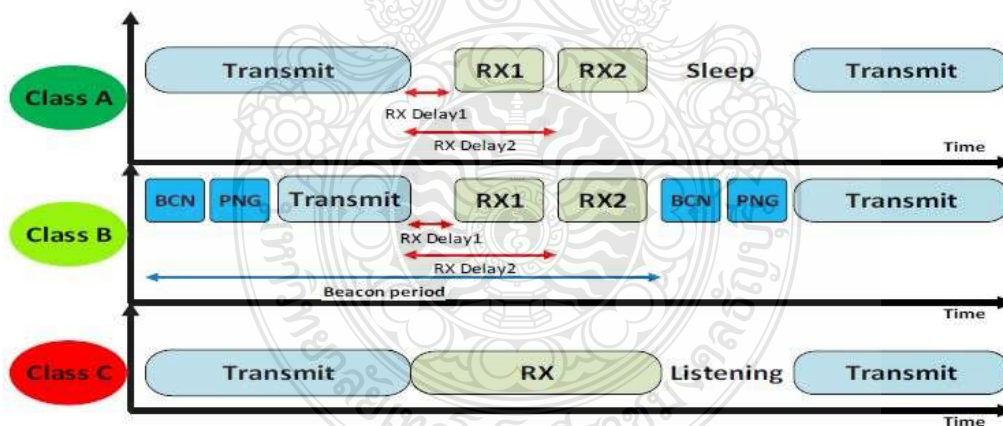


Figure 2.8 LoRaWAN device class time diagram [19]

2.3.3 Rang

Power consumption and range are two critical factors that define LoRa and LoRaWAN. When it comes to range, there may be some variations between a LoRa device's theoretical and real performance. According to SimTech, the SX1276 chip has a

range of more than 15 kilometers, however, it is unclear if this relates to urban or rural regions. In the city of Paris, France, a range measurement was performed. The results demonstrate that no packets could be received with SF 7 and 9, and only with SF 12 could 40% of data be received at the receiver's side across a distance of 3.4 kilometers [28].

2.3.4 Activation of the Device

A LoRaWAN network requires end devices to be activated and registered with the network server before they can be used in the network. Two activation techniques are provided by the LoRa standard and are thoroughly covered in [34]. The following are the authentication methods:

Over-The-Air Activation (OTAA): The network device can join any network because it does not save any hard-coded session keys while using this registration option. A Join-Request initiates the join. End devices are not customized with OTAA. If the session context is lost (for example, if the terminal restarts), the terminal must be reactivated.

Activation By Personalization (ABP): The device address and security keys are hardcoded in the edge node when a device supports ABP. As a result, utilizing ABP eliminates the necessity for the join step. However, utilizing the same session key throughout the device's use is a security risk.

2.4 Internet of Things

The Internet of Things is a technological development It can boost agricultural productivity by enhancing efficiency throughout the world's agricultural landscape [36]. The Internet of Things is a certification and accreditation for architectures where computer equipment, such as programmable logic controllers, may communicate information gathered from commonplace objects with either a final user or other machines to monitor and automate operations. The amount of equipment linked to the Internet is predicted to achieve 28 billion by 2020, according to market experts. This network of Internet-connected items gathers pertinent data using sensors for remote processing and transmission, and it provides feedback on the situation at hand and the steps that need to be taken to improve performance. When it comes to agricultural applications, these sensors often collect data on crop behavior, soil and weather conditions, animal well-being, and equipment status. clever irrigation techniques, for example, may use extra water effectively by only watering when it is necessary, in the proper amount, and on the fields that need it. In turn, this optimizes the use of resources like electricity and water as well as labor costs. Such technology developments will be essential to meeting the predicted greater production demands when paired with machine intelligence software designed to foresee potential obstacles and provide an appropriate response. The development of sensors, security mechanisms, and data management algorithms that can fully satisfy the requirements of future smart farming while remaining

ethically and economically sound is one of the unanswered research topics that have yet to be addressed.



Figure 2.9 Concept of the Internet of Things [37]

2.5 Components of IoT

The four main parts of a typical Internet of Things system are IoT devices, IoT gateway and connection, cloud and data processing, and user interface.

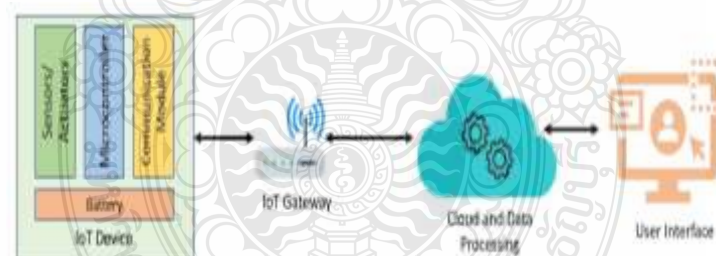


Figure 2.10 Components of IoT system [37]

2.5.1 Internet of Thing Devices

An embedded system called an Internet of Things (IoT) device includes a microcontroller or microprocessor, transducers, a communication interface for connecting to the internet through a gateway, and power supply management as needed. A sensor is a transducer that measures physical characteristics such as temperature, humidity, light, gas concentration, acceleration, and pressure. For many IoT systems, sensing is crucial. These systems frequently use a variety of data analytics approaches to

transform the raw sensor data into parameters that serve as the foundation for decision-making [38]. Many IoT devices use actuators in addition to sensors to communicate with the outside world. Since they employ an electrical signal as an input and output some physical action depending on it, actuators may be thought of as the opposite of sensors. Relay actuators are necessary for even the most basic job of remotely turning on an electrical device.

2.5.2 Internet of Thing Gateway and Connectivity

The cloud must be informed of the information the sensors or actuators have gathered. Through a gateway, the internet is connected to IoT devices. To put it simply, a gateway is a gate that permits data to go between two networks. In other terms, a gateway functions as a translational medium that enables smooth communication between two networks that use various protocols. A common example of a residential gateway is a broadband wireless router, which is found in the majority of houses throughout the world. This type of gateway uses a modem to link various LAN-connected devices to the WAN, which is run by the internet service provider (ISP). These gateways are also known as edge gateways since they may be found on the edge of a LAN and an ISP's WAN. Several communication protocols let IoT devices talk to the right gateway, which connects to the internet and occasionally also enables communication between the devices. These include Bluetooth low energy, Wireless Fidelity (Wi-Fi), ZigBee, Z-wave, LoRa, NB-IoT, and LTE-M [38]. However, depending on the recommendations, each IoT system could call for a certain communication protocol to be employed. Smartwatches and other low-power IoT devices prefer BLE for cloud communication, utilizing a smartphone as a gateway. Moreover, Low power wide area networks are expected should become standardized by Lora, NB-IoT, and LTE-M. (LPWANs) [39].

2.5.3 Cloud and Data Processing

IoT devices are intelligent not because of their capabilities but because they connect to and transmit data to other intelligent equipment, such as supercomputers that support the use of clouds. Cloud computing is one element that enhances the success of the Internet of Things. Cloud provides networking, storage, and processing power to the IoT [40, 41]. IoT systems benefit from the cloud ecosystem's flexibility, dependability, and scalability. Global access to data and additional telemetry from an IoT device can be helped by the cloud. IoT cloud-based systems combine the functionality of IoT components and cloud computing, which is provided as a seamless service. Amazon Web Services IoT, International Business Machines (IBM) Watson IoT Platform, and others are a few examples of IoT cloud platforms. The cloud may only serve as a network gateway for the devices in rudimentary IoT systems. It relates to the tools to manage and analyze raw data for complicated systems. The processed data can either be delivered directly to the user through an interface or transferred from the gateway to the Smart objects.

2.5.4 User Interface

In IoT systems, the user interface is crucial for enabling human-device interaction. They make it simple for IoT system users to simply customize devices, consume handled information, or do both. The user interface might be as simple as an encrypted message push system in the organization, online chat, short message service (SMS), or a fully-fledged browser web-based application like Twitter. The user interface assists in giving the end user information. These applications sync a cloud destination on the database server and display the data and virtual control buttons properly to make things easy for the user to understand. The end user may check in on the system thanks to the user interface. It does not always come from one side, though. Depending on the program, users may also take activities that have an impact on the system, and only a small number of actions are carried out automatically. A voice-activated user interface [42], which is predominantly used on the Internet - of - things powered by smart speakers strategies like Amazon Echo and Google Nest, is the most recent development in the field of IoT user interfaces. With their voice-activated technologies, smart speakers have accelerated the global adoption of the Network of Things.

2.6 Internet of Thing Applications

The Internet of Things has a significant impact on many apps and use cases. The following is a list of some IoT use cases and applications in real-world settings.

2.6.1 Smart cities

The problems with smart cities include resource scarcity, transportation congestion, air pollution, and water distribution [43]. In the previous years, one of the key Connectivity applications has been the monitoring of air pollution. With building automation and intelligent heating, ventilation, and air conditioning control systems for energy-efficient activities, smart and green buildings are a crucial component of smart cities. IoT networks aid in enhancing the energy management system's effectiveness and quality of service (QoS). Additionally, it would facilitate control and provide an equitable allocation of authority among the citizens of the many cities[44]. While ensuring that these cities are sustainable, responsive, meaningful, and have growing economies, the goal is to boost local area development, leverage technology, particularly that which delivers smart outcomes, and improve people's quality of life.

2.6.2 Connected Industry

Industry 4.0 and the Smart Factory are built on the Internet - of - things, which links smart factories, machines, infrastructure facilities, management systems, and more to speed up company operations and create intelligent, self-optimizing industrial equipment and facilities [45]. Innovative IoT solutions may be used to solve a range of problems relating to the management of resources, security, and human safety. Due to

LoRaWAN's exceedingly low power requirements, which are ideal concerning the industrial automation industry, the Industrial IoT represents a quickly expanding field of application for low-power wide-area networks. Innovative services are made possible by LoRaWAN to increase the effectiveness, dependability, and accessibility of manufacturing applications and goods.

2.6.3 Health care

IoT technology is changing how we receive healthcare and providing sponsors, medical professionals, and patients with cutting-edge information and analytics [46]. Companies in the healthcare, pharmaceutical, and life sciences industries may make better decisions and gain a competitive edge thanks to the data collected through IoT devices. Real-time illness monitoring and treatment will evolve as a result of IoT breakthroughs and its ongoing collaboration with the pharmaceutical and healthcare industries. The current COVID-19 epidemic has accelerated the usage of IoT in healthcare. IoT has enabled remote patient diagnosis and treatment during periods of physical separation.

2.6.4 Smart grids

The electric grid is a network of power stations, transformers, transmission systems, and other parts that carry energy from a power plant to your home or place of business. Electricity generation will embark on a new age of easy accessibility and dependability, and effectiveness with the implementation of the Smart Grid, which will enhance both our economic status and the ecosystem. The goal of the smart grid is to reduce how much energy is used by buildings. For millions of buildings connected across several cities, IoT networks are utilized to boost energy management system effectiveness and service quality. Additionally, it makes it possible to govern the population easily and distribute electricity proportionally throughout the cities [47].

2.7 Challenges in IoT

To fully exploit the present and future potential of IoT, several obstacles and hurdles must be overcome. Here is a handful of them that demand your attention:

2.7.1 Low-cost sensors

Traditional sensing devices frequently need significant resources, infrastructure, and experience; they are known for their high purchasing costs and complicated installation processes. With these options, high density is impossible, leaving a lot of gaps in the dataset that has been gathered. High-resolution spatiotemporal measurements provided by cheap sensors might enhance the datasets from conventional environmental monitoring technologies. However, as low-cost sensors are frequently

impacted by field circumstances, frequent calibration is necessary for them to deliver correct and trustworthy data. This is one of the key problems influencing the quality of the data collected.

2.7.2 Deployment Issues

The Internet-of-Things (IoT) is being attached in more fields than only consumer-based ones, such as the Internet of Medical Things, autonomous vehicles, systems engineering, emergency response, and public health and safety. It is crucial to do these procedures correctly since many of them are mission-critical tasks with potentially fatal consequences. During the critical phases of initial implementation, deployment, and subsequent maintenance, it is essential to have confidence that the system can be deployed, supported, and maintained for all necessary equipment and infrastructure. Obtaining authorization from the appropriate authorities, choosing the best deployment area, obtaining people's agreement to have their data collected, and many other challenges may arise. The deployment phase is the culmination of all prior planning for security and data privacy, testing and enabling interoperability, forward stocking of backup hardware, customer support, technical support for Area network or internet connection, access points, browser extensions, applications, and your cloud hosting.

2.7.3 Power Management

It's critical to amplify the battery life of IoT gadgets because the majority of them run on batteries. Due to the sensor node's low energy capacity, it is one of the essential resources that must be well controlled. A key problem in extending a sensor node's lifetime is when the node is difficult to reach or requires a lot of maintenance. For an IoT solution to be resilient and scalable, the lifespan of sensor nodes is also crucial.

2.7.4 Connectivity

It is crucial to have dependable and smooth connectivity since there will be numerous devices linked to the internet and each other. Data transit depends on strong connectivity, making connectivity one of the key IoT components. So, for IoT networks, having the correct connectivity is essential. There are several alternatives accessible, whether it is for the end equipment, the connection component, the middleware, or the back-end systems. Connectivity is made possible via communication protocols like 802.15.4, Bluetooth, ZigBee, etc. In the case of IoT, there may be some connectivity-related problems, including excessive power consumption, dependable bidirectional signaling, appropriate bandwidth use, etc. NB-IoT, LoRaWAN, IEEE 802.11ah, and other communication technologies will be the game changers in resolving connectivity problems[48].

2.7.5 Interoperability

The capacity of two or more systems, platforms, networks, or devices to cooperate is known as interoperability [49]. To accomplish the shared objective of end-to-end interoperability of multiple heterogeneous devices, services, and applications, interoperability permits communication between heterogeneous devices or systems. To assure compatibility and interoperability with other devices, smartphones employ a variety of communication technologies, including Wi-Fi, Bluetooth, cellular networks, and near-field communication.

2.7.6 Privacy and Security

Data security is a serious problem since the increase in devices being deployed in uncontrolled and remote locations in dangerous conditions [50]. Executing complicated cryptographic processes for secure communication, over-the-air updates, and data privacy is challenging due to the resource limitations of IoT equipment. The security of IoT devices is further complicated by the usage of hard-coded weak passwords, a lack of consistent patching, insecure interfaces, fragmented security standards, and skill shortages. The difficulties include managing over-the-air security upgrades, managing data privacy and integrity, safeguarding resource-constrained devices that can't quickly conduct complicated encryption and decryptions, etc. Other significant security problems include providing secure communication between devices connected to a network and in the cloud, as well as protecting online and mobile apps that handle user data.

2.8 The Global Positioning System (GPS)

A constellation of 31 uniformly spaced satellites known as the global positioning system, or what we call GPS, circles the earth and enables users of ground receivers to pinpoint their precise location. With specialized, military-approved equipment, the location precision is as close as one meter while it is between 100 and 10 meters with standard equipment. Since GPS technology is so widely utilized in science, it is now affordable enough for practically everybody to acquire a GPS receiver. The US department of defense first created GPS for military use in the 1970s. But because it now serves both the military and the civilian population and is a dual-use system, it was eventually made available to people. However, the GPS is regarded as a one-way (passive) system because it can only be used by users to receive the signal.



Figure 2.11 Ublox NEO-7M GPS Module [51]

Maximum sensitivity is offered by the NEO-7 (datasheets) [51] series while still requiring little system power. While the NEO-7N offers the best performance and simple RF integration, the NEO-7M is targeted for applications with a tight budget. Migration from earlier NEO generations is simple thanks to the NEO form factor. Even in GNSS-hostile conditions, advanced RF architecture and interference mitigation guarantee maximum performance. The NEO-7 series offers numerous connectivity options and high levels of integration capability in a small package. As a result, it is suited for engineering settings with strict type and budget requirements. The u-blox SARA, and LISA cellular elements can communicate with one another and work together effectively thanks to the I2C-compliant DDC interface. The u-blox 7 modules are made in ISO/TS 16949 authorized factories using GNSS chips that have received AEC-Q100 certification. The mandatory qualification tests are defined in the ISO16750 minimum requirement, Road vehicles - Physical environment and testing for electrical and electronic equipment.

2.9 Microcontroller (MCU)

Nowadays, the microcontroller is currently used in electrical appliances, electronic devices, and industrial plant systems. Practically all controllers have been placed inside of them, making microcontrollers one of the gadgets that many semiconductor makers use. The business is attentive and fiercely competitive. Devices that are controlled by microcontrollers include programmable logic controllers (PLCs), computer numerical control (CNCs), robots, and many more. Single-chip microcomputers, such as the PLC series of microcontrollers, are frequently utilized. Therefore, learning about microcontrollers requires continuous study of several different topics, including electronic circuit design and microcontroller architecture. An embedding software's microcontroller is a small electronic circuit that manages a single process. The standard microcontroller consists of a single chip with a CPU, memory, and input/output (I/O) devices. Microcontrollers sometimes referred to as integrated controllers or embedded systems are technological parts utilized in a broad range of gadgets, such as automation, vehicles, coffee machines, office supplies, and medical devices. They function essentially as simple, diminutive desktop computers without a

complex front-end computer system, used to control, discrete functions of larger component operating systems (OS). To control a single device function, a microcontroller is integrated A microcontroller is embedded within a technique to maintain single hardware performance. It does this by viewing data that it gets for its input and output components using its core central processing unit. The machine of the microcontroller connects the provisional files contained in its reconnection space, where it is accelerated using code memory instructions to interpret and apply the incoming data. It then uses its input and output ports for transmission and performs the necessary operation.

2.9.1 Arduino Nano Mini-B USB CH340G

The Arduino Nano features a USB incorporated into an embedded surface mount breadboard version of the board. Considering the ATmega328P is a little, compact, thorough, and breadboard-friendly board. There are more analog input pins and an inbuilt +5V jumper in addition to everything that provides in terms of electrical features. There is no power jack on the outside of it. Nano will mechanically identify and split to a greater possible power generator without the requirements for a power-choose adolescent. Customers can fit more breadboard space on their breadboards thanks to Nano's lower footprint than either the boarding or the Mini-B USB.

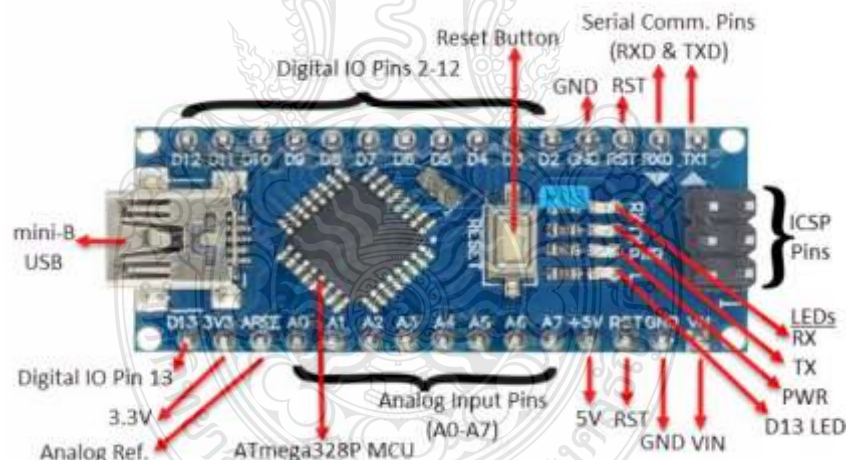


Figure 2.12 Arduino Nano [52]

It has a slot configuration that is effective with the small or the simple symbol TX, RX, VIN, and Ground at the top, ability, and ground on the other. They also function well as general-purpose input/output pins. The integrated development environment (IDE) software that Arduino has developed fully supports the C and C++ programming languages, and the ATmega328P in this enhanced version 3.0 offers more room for data and programming. A microcontroller serves as the primary controller for the circuit. With the help of the Arduino system, a variety of boards and circuits can be attached to a set of analog and digital pins to carry out various functions in a design. This

lowers the cost and makes it simpler to hack. It features 14 input/output pins, 6 of which may be used as power regulator (PWR) output, 8 circuit ports, a 16 MHz crystal oscillator, a small USB, an ICSP header, and a reboot button. It should be noted that the firmware for ATmega328P is programmed via the In-Circuit Serial Programming header, but typically the chip has already been burned before leaving the factory. Consequently, utilize it less frequently. The mini-B USB port or female headers VIN/GND can be used to power the Arduino nano (DC 7-12V). You can also use an external, controlled 5V power supply to power your Arduino through the 5V pin. Either a DC-to-DC converter attached to a battery or group of batteries, or a wall adapter that continuously outputs 5V can be used.

2.9.2 CAT Starter kit S767S

The CAT LoRa Starter Kit has an integrated temperature and humidity sensor as well as an AcSIP S76S LoRaWAN chip that operates at frequencies of 868 MHz or 915 MHz (HTS221). These are some of its specifications, as shown below:

1. Operation Mode: LoRa Modem (AT Command)
2. AS923 Frequency 920-925
3. ARM Cortex-M0+ CPU up to 48MHz
4. LoRa Module: Acsip S76S
5. Memory 256KB internal self-programming Flash, 32KB SRAM
6. Digital 9-Pin, Analog 6 Pin
7. Hardware Serial, I2C, SPI support
8. Operating Voltage 3V
9. Length 76.20 mm x Width 25.4 mm



Figure 2.13 Board CAT Starter kit S767S [53]

2.10 Sensor

The most significant function of the sensors system is the mechanism for detecting water quality. For the system to be automated, sensors are necessary. Without their help, the system cannot be suggested as being fully autonomous. In its broadest definition, a sensor's function is to identify activities or environmental improvements and relay that data to additional electronics, most usually a processor for a computer. With a detector, other electronics are constantly used. Sensors are utilized in commonplace items like tactile elevator buttons, a little button for tunnels, and lighting that you can terrible or brighten by touching the base, among countless additional uses that most people are unaware of. Due to advancements in micromachinery and user-friendly microcontroller-based systems, the application of sensors has expanded past the typical disciplines of temperature, force, or flow monitoring. Also still widely used are analog sensors like force-sensing resistors and potentiometers. Robotics, healthcare, aerospace, caregiving, and many other parts of daily life are just a few examples of the diverse spectrum of applications. Sensors of various types measure the chemical and physical properties of materials. An optical sensor for detecting refractive index, a vibrational sensor for figuring out fluid viscosity, and an electrochemical sensor for figuring out fluid pH are a few examples. An electrical signal is released by a sensor in reaction to events or changes it detects in its environment. The most important sensor characteristics are speed, linearity, precision, and resolution. Performance can be enhanced by the sensor. Structure-related faults can be located by comparing the observed and expected outputs of a sensor. Repetitive mistakes that were during calibration and computation are rectified true during dimensions taken by sensors. We talk about each type of sensor because there are many different kinds.

2.10.1 Temperature Sensor (DS18B20)

Using a single bus, the temperature sensor is digital. The temperature range of this sensor, which communicates with the CPU through a single bus port, is 55 to 125 Cecil ($^{\circ}\text{C}$), with an incremental value of 0.5°C . Different DS18B20s may function on the same 1-Wire bus thanks to each device's specific 64-bit serial code, and the temperature can be translated into numbers in less than 720 milliseconds. The DS18B20 has No. 0 and No. 1 as its accessible 8-bit storage for recording temperature readings. The temperature value is complemented by No. 0 storage stores, whereas No. 1 storage stores represent the temperature value. As a result, it is easy to use. a single integrated circuit to manage several DS18B20s that are dispersed across a sizable region [54].



Figure 2.14 Temperatures Sensor [54]

2.10.2 Turbidity Sensor (SEN0189)

The turbidity sensor assesses the turbidity rate and opacity to determine the water quality. The sensor measures the intensity of light dispersion and light absorption for canceled components in water, this varies according to the water's overall suspended solids content. The sensor system in question also includes an amplifier board. There are only three pins needed to connect the module to Arduino: VCC, GND, and SIGNAL. In the turbidity sensor, a light transmitter and receiver are employed. Cleansed waters have a low light dispersion, which suggests that the light receiver takes the lightest. As the turbidity of the water increases, the light receiver receives less illumination. The sensor is activated if the amount of received light falls below a predetermined threshold. Notably, this amplifier board has a mode switcher that can switch between analog and digital modes. Assume that the digital mode is being used just to determine whether the water is excessively turbid. Turbidity levels must be measured using the analog mode. The sensor has a reaction time of less than 500 ms, a max operating current of 40 mA, and an operating voltage of 5 V dc [54].



Figure 2.15 Turbidity Sensor [54]

2.10.3 pH Sensor (SKU: SEN0161)

The analog potential of the hydrogen sensor is specifically designed to determine if a solution is acidic or alkaline. The pH sensor often takes the shape of a glass rod-shaped device, with a bulb covering the sensor's underside. The electrode for measuring pH is connected to a glass bulb designed to be a very accurate hydrogen-ion concentration detective. The positive polarity ions on the reference electrode react with the hydrogen ion in the test solution to create an electrochemical potential/potential difference across the bulb when the glass electrode is submerged in the water for analysis. The electronic amplifier measures the electrical potential difference between the pH and reference electrodes by converting it to pH units. The electrochemical potential of a glass bulb is inversely proportional to pH, according to the Nernst equation. It is straightforward to determine the pH values of various aqueous solutions with this pH sensor [54].

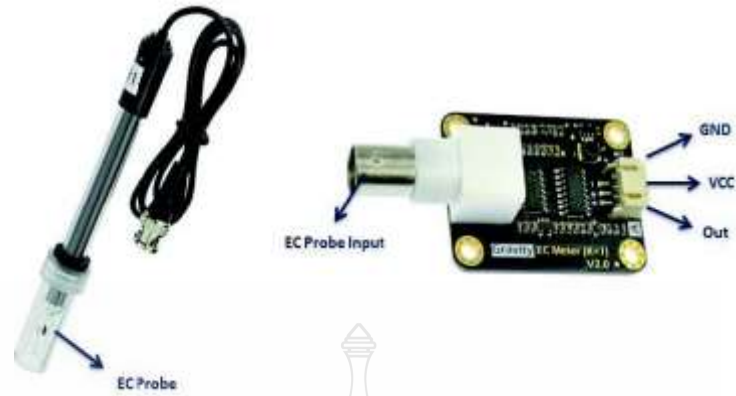


Figure 2.16 pH Sensor [54]

2.10.4 Conductivity Sensor (SEN0244)

Salts break down into positive and negative ions when they dissolve in water. The conductivity of water determines how well it can carry an electrical current, which is made up of dissolved ions. The main negatively charged ions are chloride, sulfate, carbonate, and bicarbonate, whereas the main positively required pay ions are sodium, calcium, potassium, and magnesium. Phosphates and nitrates are insignificant charged ions that affect conductivity. A probe and meter are used to measure the electrical conductivity. The probe has two metal electrodes that are separated by one centimeter (unit: mili- or micro-Siemens per cm). Across the electrodes, a fixed voltage is delivered. The electrical conductivity of water is measured by the current flow through it, which is proportional to the number of dissolved ions present [55].



Figure 2.17 Electrical Conductivity Sensor [55]

2.10.5 Dissolve Oxygen Sensor (SEN0237)

One of the key parameters used to assess water quality is dissolved oxygen. Low dissolved oxygen levels in water make breathing difficult for aquatic organisms, potentially endangering their lives. We've released a new open-source dissolved oxygen sensor kit that works with Arduino. This product is used to determine the amount of dissolved oxygen in water, which reflects the water's quality. It is widely used in a variety of water quality applications, including aquaculture, environmental monitoring, natural science, and others. This sensor kit allows you to quickly construct your own dissolved oxygen detector. The probe is a galvanic probe that does not require polarization time and thus can measure at any time. The filling solution and membrane cap are replaceable, resulting in low maintenance costs. The signal converter board is easy to use and has high compatibility. It can be easily integrated into any control or detection system. This product is simple to use and highly adaptable. This product is ideal for your water projects for detecting the dissolved oxygen concentration in aquatic organisms because it comes with open-source code and a detailed tutorial.



Figure 2.18 Dissolve Oxygen Sensor [56]

2.11 Solar Panels

The sun serves as the sun energy's source. Photovoltaic systems another name for solar cells produce electricity that may be used to power electrical devices by using photons, the tiny energy particles that make up the sun's light. Solar panels may be utilized for a wide range of other applications to generate maximum electricity for both residential

and commercial solar electric systems, including remote power systems for cabins, satellite systems, remote sensing, and more.

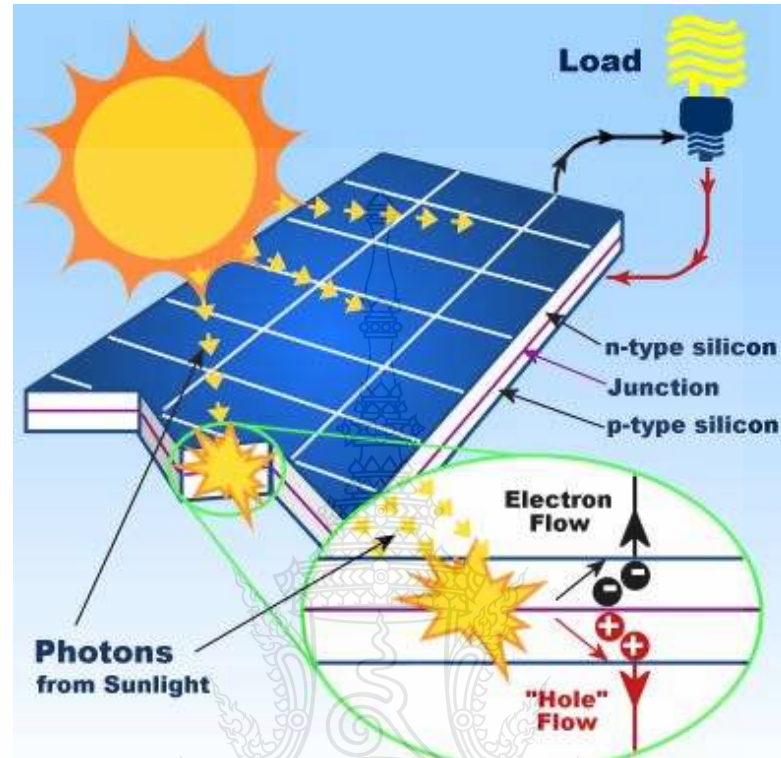


Figure 2.19 Process of Solar Panels [57]

2.11.1 How solar panels function

Solar energy is collected and converted into electricity from solar panels, which is then used to power electrical loads. The negative charge is produced by the layers of silicon, boron, and phosphorous that make up the individual solar cells that makeup rooftop solar. Solar panels receive photons, which ignite an electrical circuit. Electrons may be ejected from their number of protons and neutrons and released into the solar cells' electric field, where the electric field pulls them into a directed current. The energy generated as a result of photons striking the solar panel's surface makes this procedure feasible. The entire procedure is known as the photovoltaic effect. The number of solar panels needed to generate enough solar energy to satisfy all of a normal home's energy needs may be installed on the roof with more than adequate room. The main power grid receives any excess energy, which lowers nighttime electricity use.

2.11.2 Advantages of Solar Panels

Solar power is a highly practical approach to providing a range of demands with electricity. Off-grid living would seem to be the most logical choice. Living off-grid means not having a connection to the main electric utility grid. In distant locations, solar power systems are a fantastic advantage for cabins and homes. When done at a distance from the nearest main grid access point, installing electric utility poles and lines is no longer unreasonably expensive. A solar electric system may be less expensive and produce power for up to three decades if properly maintained. Solar panels make it possible to live off-grid, but the largest benefit you would experience from using solar power is that it is a sustainable and clean source of energy. We must act now more than ever to reduce the strain that greenhouse gas emissions are putting on our environment as a result of the beginning of global climate change. Solar energy requires minimal care because there are no moving parts. With routine maintenance, they are sturdily constructed and survive for many years. The last and most significant advantage of solar energy and panels is that they will continue to provide electricity for free after they have paid for themselves, which might take somewhere around 15 and 20 years depending on the system's quality. As soon as the system is operational, owners of grid-tied solar power systems gain benefits, either by ceasing to pay monthly energy bills or, and this is the greatest part, by actually boosting their utility earnings. How? If you consume less energy than your solar electric system generates, you may sell the extra energy to your electric utility provider, sometimes for a premium.



CHAPTER 3

HARDWARE DESIGN AND IMPLEMENTATION

The methodology setup and configuration are going to be described in chapter 3. Following is a detailed explanation of the working system design, structural design, and the working test method. In the development and design of hardware and software based on IoT and LoRaWAN to monitor the quality of water through the internet that is effective and capable of achieving the goals. To operate effectively, meticulous planning is required. It goes without a problem when you break it up into several steps detailed in the following.

3.1 Hardware Configuration

The structure below was created for a water quality monitoring system that compares the quality of the water and measures the fine percentage error value of the sensor. This solar cell power crystalline silicon photovoltaic module that we installed with this system open circuit voltage (vmp) 37 volts of electricity to direct current circuit the solar energy is converted into electricity reduce source powered from its to dc-to-dc step-down LM2596 (8 voltages) then recharge LG 18650 HG2 3000mAh 20A Lithium battery at 7.2 voltage and the power reduced from battery to 7 voltages on the dc-to-dc step. Additionally, there will be a 5-volt drop on the CAT Starter kit S76S board (AtsamD21 Cat LoRaWAN), Arduino nano (ATMega328), and the five sensors connected to it. The global positioning system (GPS) module will provide location data to the Arduino Nano, and five sensors will communicate with the CAT Starter kit S76S to transmit readings for conductivity, temperature, pH, turbidity, and dissolved oxygen. The hardware must be built with a powerful main processing unit, as well as all the switches for the sensors, general maintenance, easy connections to other materials needed, and reconfiguration or improvement, to always be maintained and used properly. As seen in Figure 3.1, the CAT Starter kit S76S board has sensors for turbidity, temperature, the potential of hydrogen (pH), electrical conductivity dissolve oxygen, and a microcontroller that serves as the main processor. Especially, one more microcontroller we use is the board of Arduino Nano is linked to the GPS module M7, and both are interconnected to the board CAT Starterkit Gravitech S76S. A direct current converter generated through a photovoltaic cell supplies the charge voltage of the battery for the CAT Starterkit Gravitech S76S.

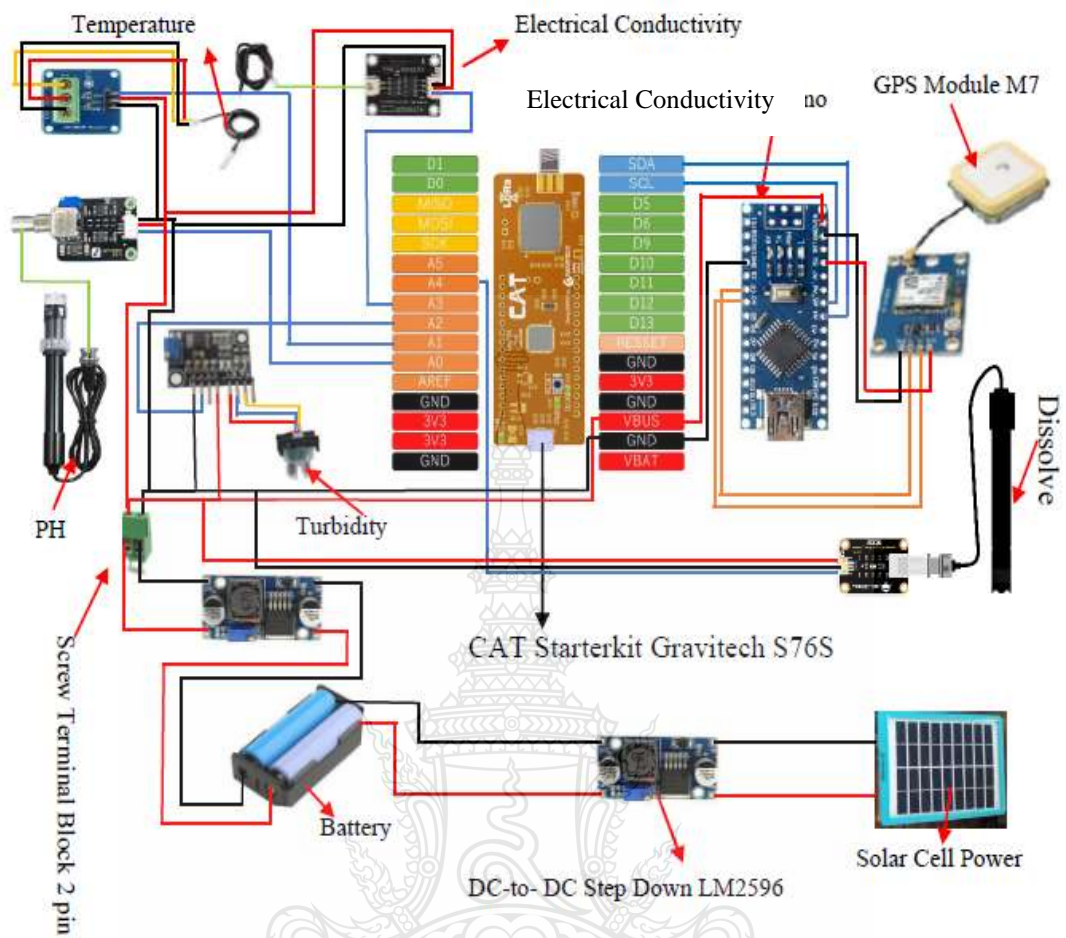


Figure 3.1 Structure of Hardware Design

Installation guidelines for attaching the temperature sensor to the CAT Starterkit Gravitech S76S board are given, as shown in Figure 3.2 below. Additionally, the temperature sensor port data connected to the pin A1 of the CAT Starterkit Gravitech S76S, as well as the power supply port connected to the screw terminal block pin2 (5V), and the ground-connected GND.

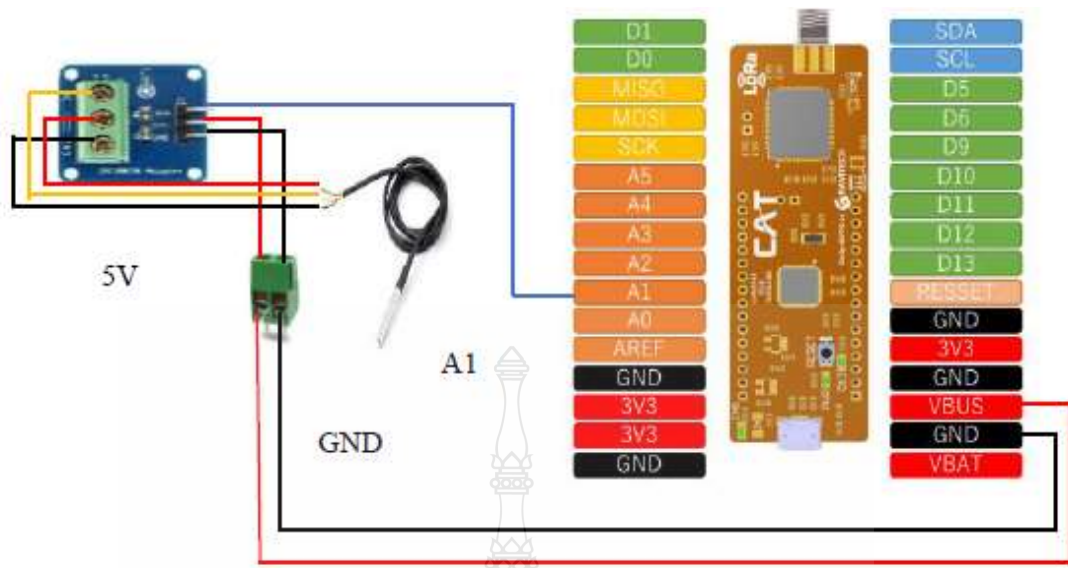


Figure 3.2 Temperature Sensor with CAT Starterkit Gravitech S76S

Include the library, then declare the `OneWire` and `DallasTemperature` objects for the pins connected to the data pins of the sensors.

```
#include <OneWire.h>
#include <DallasTemperature.h>
#define ONE_WIRE_BUS A1
```

Send the command to read the temperature in Celsius (°C) after that.

```
sensors.requestTemperatures();
float Temp = sensors.getTempCByIndex(0);
```

Furthermore, a connector (P0) linked to the (A0), a ground pin strongly connected to GND, and a power supply cable connected to an insert screw terminal block pin are all used to connect the potential of the hydrogen sensor, also known as a potential of hydrogen sensor, to the CAT Starterkit Gravitech S76S board (5v).

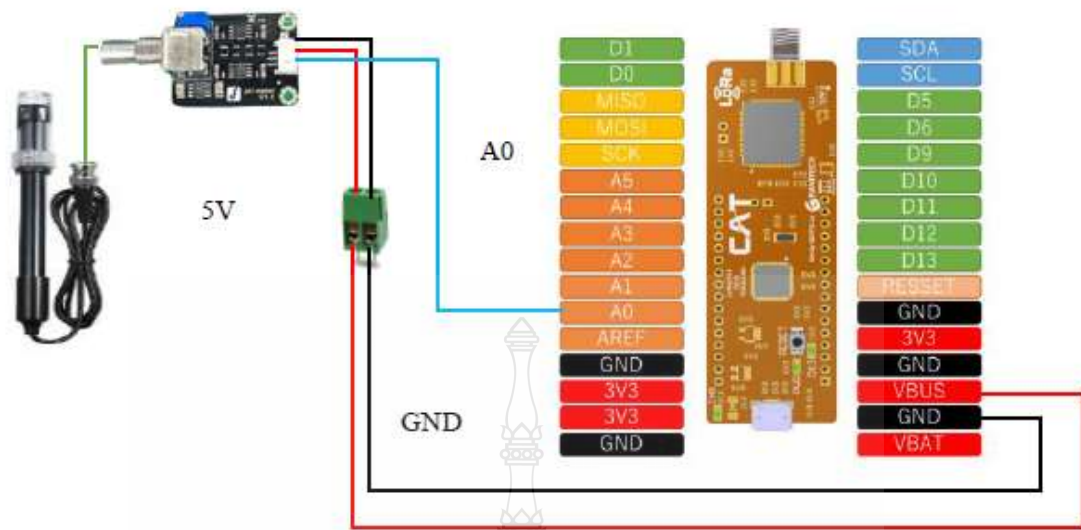


Figure 3.3 pH Sensor with CAT Starterkit Gravitech S76S

Declare the pH meter Analog output to Arduino (A0) as pin Input after the pH sensor and microcontroller have been connected. Use an offset to account for deviations and an unsigned long int value to store the average value of the sensor feedback.

```
#define SensorPin A0
#define Offset 0.00
unsigned long int avgValue;
```

Read 10 representative analog values into an array inside of a loop(). To smooth the output value, this is necessary.

```
for(int i=0;i<10;i++)
{
  buf1[i]=analogRead(SensorPin);
  delay(10);
}
```

Then, order the received analog values in ascending order. This is necessary because, at a later stage, we must determine the running average of the samples.

```
for(int i=0;i<9;i++)
{
  for(int j=i+1;j<10;j++)
  {
    if(buf1[i]>buf1[j])
    {
      int temp=buf1[i];
      buf1[i]=buf1[j];
      buf1[j]=temp;
    }
  }
}
```

The average of a six-center sample of analog values should then be determined. The analog value of this average value is then converted to millivolts, and the millivolts are then converted to pH values.

```
avgValue=0;
for(int i=2;i<8;i++)
  avgValue+=buf1[i];
float pHValue = 1;
float pHValue1=(float)avgValue*5.0/4095/7.5;
float pHValue2=3.5*pHValue1 + Offset;
if (pHValue2 > 0){
  pHValue = pHValue2;
}
```

The CAT Starterkit Gravitech S76S board is connected to an electric conductivity sensor, the ground pin has always been connected to GND, and electricity generation is closely related to the screw terminal block pin (5V) wire, and (A3) is connected to (A1 analog slot).

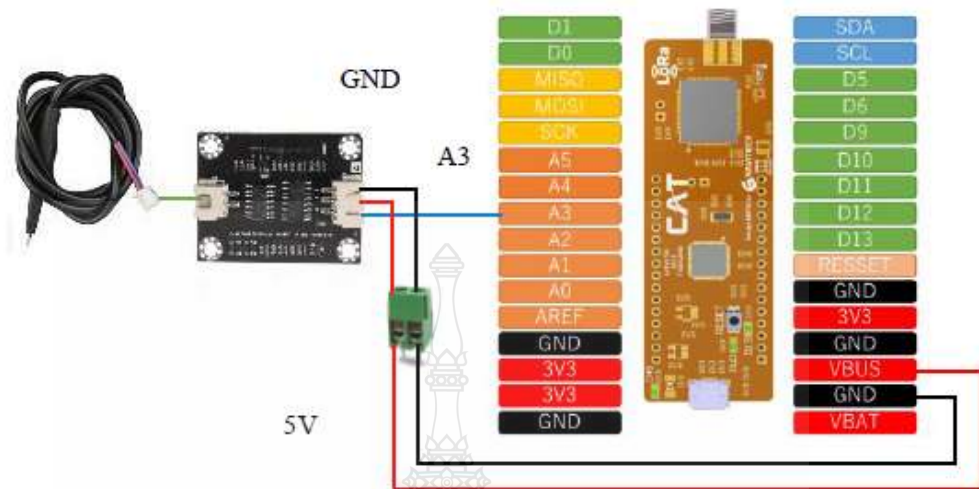


Figure 3.4 Electrical Conductivity Sensor with CAT Starterkit Gravitech S76S

After the Electrical Conductivity Sensor and Microcontroller are connected, open the Arduino IDE and declare a (voltage) and (ECValue) variable of type (float) at temperature 25 (°C) and configure pin (A3) as input.

```
#define EC_PIN A3
float voltage, ECValue, temperature = 25;
pinMode (A3, INPUT);
```

Lastly, read the voltage analog and convert it to electrical conductivity.

```
float voltage = analogRead(EC_PIN) / 1024.0 * 5000;
float ECValue = voltage / 100 ;
```

The turbidity sensor is specifically connected to the CAT Starterkit Gravitech S76S by connecting the ground to the GND, the power source to the (5V) of the screw terminal block pin, and line (A analog) insert with the turbidity sensor (A2).

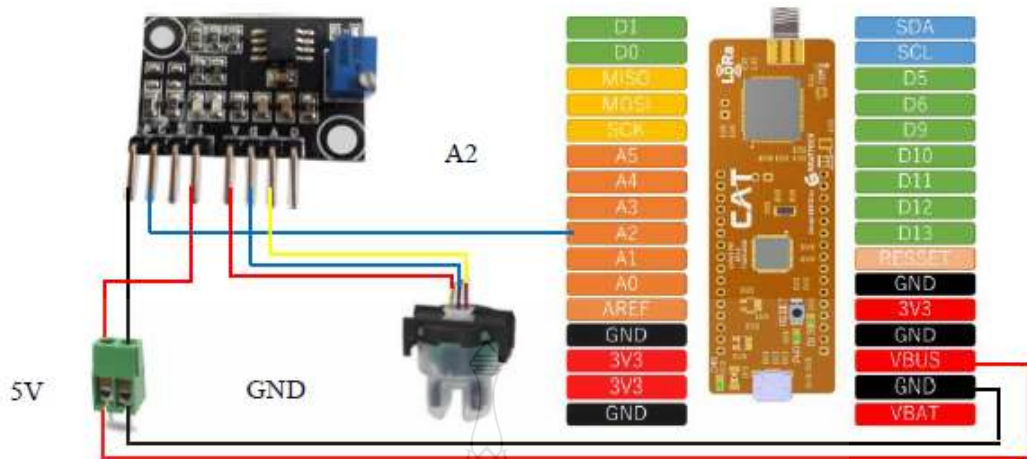


Figure 3.5 Turbidity Sensor with CAT Starterkit Gravitech S76S

Once Turbidity has been installed, open the Arduino IDE and declare the (volt) and (ntuTb) variables as being of type (float), and then configure pin (A2) as input.

```
float volt;
float ntuTb;
pinMode(A2, INPUT);
```

The sensor's output analog voltage has large fluctuations and is too noisy to measure. Thus, we calculated the average reading value using the 800 readings.

```
volt = 0;
for(int I = 0; i < 800; i++)
{
    volt += ((float)analogRead(sensorPin) / 1023) * 5;
}
volt = volt / 800;
```

We converted the analog voltage value to NTU using this formula.

```
float ntuTb = -1120.4 * (volt * volt) + 5742.3 * volt - 4353.8;
```

The NTU is set to 3000 if the analog voltage reading falls below 2.5 V. Therefore, the maximum NTU value is 3000.

```

if(volt < 2.5)
{
  ntu = 3000;
}

```

The dissolved oxygen sensor is specifically connected to the CAT Starterkit Gravitech S76S by connecting the ground to both the GND and the ground, the sensor's power source is configured with screw terminal block 5V, and line analog insert with A4.

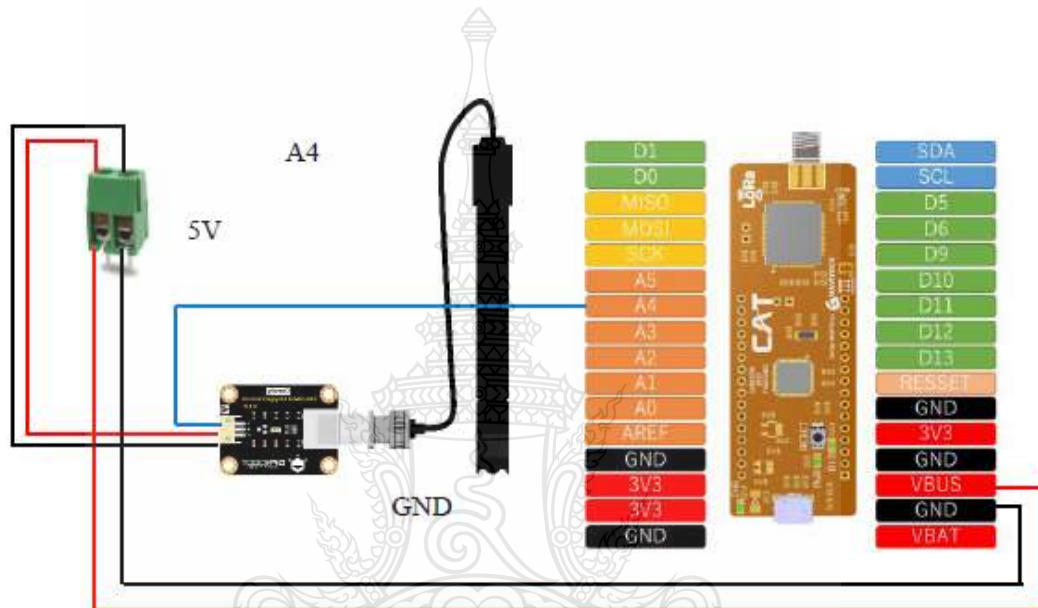


Figure 3.6 Dissolve Oxygen Sensor with CAT Starterkit Gravitech S76S and Arduino

To create your own dissolved oxygen meter, upload the following code to an Arduino board. Change the voltage and temperature values in the following line of the code. It is recommended that the calibration be performed at a temperature of 25 °C.

```

#define CAL1_V (1600) //mv
#define CAL1_T (25) //°C

```

We are defining this line because we are using the single-point calibration method.

```

#define TWO_POINT_CALIBRATION 0

```


If you want to perform a two-point calibration, you should also modify the voltage and temperature parameters from these lines.

```
#define CAL1_V (1600) //mv  
#define CAL1_T (25) //°C  
#define CAL2_V (1300) //mv  
#define CAL2_T (15) //°C
```

The global positioning system (GPS) Module NEO-M7 ground pin is directly linked to just the GND on the board Arduino Nano the 5Volt power generation responds to 5 volts of screw terminal block pin, and the received data (RX) is tied with D3 and transmits data (TX) is linked to D4 as seen figure 3.7 please refer to the following.

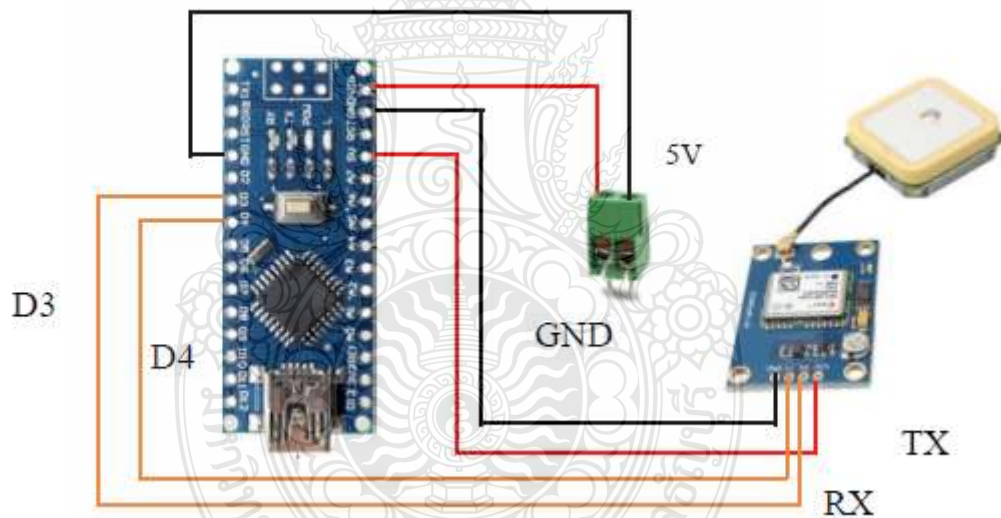


Figure 3.7 GPS Connected with Arduino Nano

First, the SoftwareSerial.h library is excluded because software serial will be used to connect the two devices.

```
#include <SoftwareSerial.h>
```

To establish serial communication with the GPS module, this sketch assumes that pin4 and pin3 will be used as RX and TX serial pins, respectively.

```
static const int RXPin = 4, TXPin = 3;
```

The serial communication for the Arduino port and the GPS port will be opened in the setup() function at a baud rate of 115200.

```
void setup()
{
  Serial.begin(115200);
  gps_Serial.begin(GPSBaud);
}
```

We will read the GPS port inside the loop() function and print the information in the serial monitor.

```
void loop() {
  while (gps_Serial.available() > 0)
  {
    gps.encode(gps_Serial.read());
    if (gps.location.isUpdated())
    {
```

Figure 3.8 illustrates the close relationship between the Arduino board and the CAT Starterkit Gravitech S76S microcontroller. Using swap pins A4 and A5 are connected to the microcontroller's pins for serial data and clock, respectively, and the Arduino board's USB port is connected to the microcontroller's port for the universal serial bus (USB). In addition, the GND of each microcontroller is linked to GND, and the source power supply is connected to the pin with a (5V) voltage on the screw terminal block.

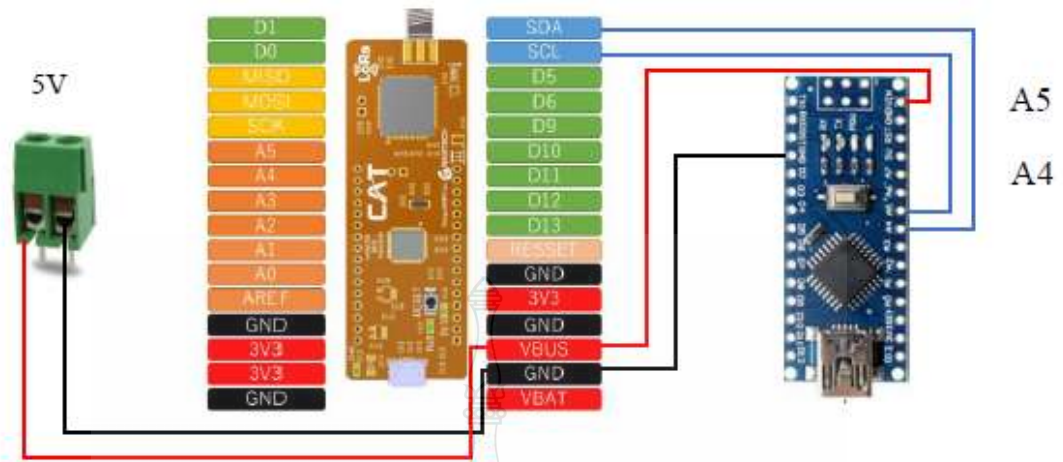


Figure 3.8 Arduino Connected with CAT Starterkit Gravitech S76S

Figure 3.9 below shows the structure of the installation and how to reduce the power supply open-source circuit by 37 volts from the solar power cell to the first dc-to-dc step-down LM2596 (8 volts). Moreover, LG 18650 HG2 3000mAh 20A lithium battery reduce the power source from (7.2 volts) to (7volt) second dc-to-dc step-down and finally screws the terminal block pin 5 volts to use all microcontroller and sensors to operate in this system.



Figure 3.9 Screw terminal block connected with solar cell.

This floating buoy was created to automatically measure water quality parameters such as temperature, conductivity, turbidity, the potential of hydrogen, dissolved oxygen, and GPS location in front of the department of electronics and telecommunication engineering using a wireless network. LoRaWAN is used to transmit

data over a long, kilometer-long maximum range. It is a device to help support the aerator above the water by using buoyant force. Most materials are made from polyethylene (PE) plastic, which has tough properties and is heat resistant. The dimensions of the outside box floating buoy have a height of 0.9m, width of 1.16m, and length of 1.7m, as shown in more detail in figure 3.10 below. We use solar cells of the Crystalline Silicon Photovoltaic Module type BQ-120M-370W, which weigh 19.5 KG and measure 1755x1038x35 (mm), connected to the control box to charge the batteries for the entire operating system. In addition, the propeller's rotation and contact with the water's surface depend on the motor's propulsion. The propeller's beating will agitate the water and aerate it horizontally, increasing the amount of dissolved oxygen in the water, which is great for the different types of propellers used in wastewater treatment systems.



Figure 3.10 Details of the outside floating buoy

3.2 Software Configuration

The board CAT Starterkit Gravitech S76S and Arduino Nano 3.0 microcontroller are programmed using C++ Programming language data from sensors received and saved using the Arduino integrated development environment. The programming entailed the library declaration which was obtained and submitted to the integrated development environment (IDE) to be used by the sensors used in the board CAT Starter kit and GSP the Arduino microcontroller, as well as void setup and void loop which are necessary for the C++ programming language.



Figure 3.11 C++ Programming and Arduino IDE

All sensors are initialized when the operation starts, and then sensor acquisition processing is performed. If the editor receives the message "No," it is advised that they check the operation again to identify the source of the problem. By the way, if the message "Yes" is displayed, the entire sensor has been successfully read, at which point the process will start. If not, the potential of the hydrogen parameter is calculated by averaging the voltage used to convert the analog into millivolts and then converting the millivolts into the potential of hydrogen value, using the average of the 10 sample values obtained from the sensor to smooth the value and sort the analog from small to large. Recommend a sensor temperature value and build a temp object of type float using the library. Additionally, because of the sensor's output analog voltage's extreme variability, it is not possible to measure it according to turbidity. To calculate the reading value, we, therefore, averaged 800 readings. Using this formula, we converted the analog voltage value to NTU. Electrical conductivity declares that a variable is analog by reading its value from an integer-type variable, calculating it, and converting it to volts. Modify the following line of code to define the variable of the float type generated from the electrical conductivity value trend equation and dissolve oxygen as with temperature and calibration voltage. The calibration should be done at a temperature of 25 °C, if possible. Additionally, the Cayenne LPP platform matte finish sensor readings are saved in the `_payload` variable. Once the LoRa transmission conditions and communication parameters have been chosen and met, the serial monitor will display the message "Send Payload OK" for the transmitted payload.

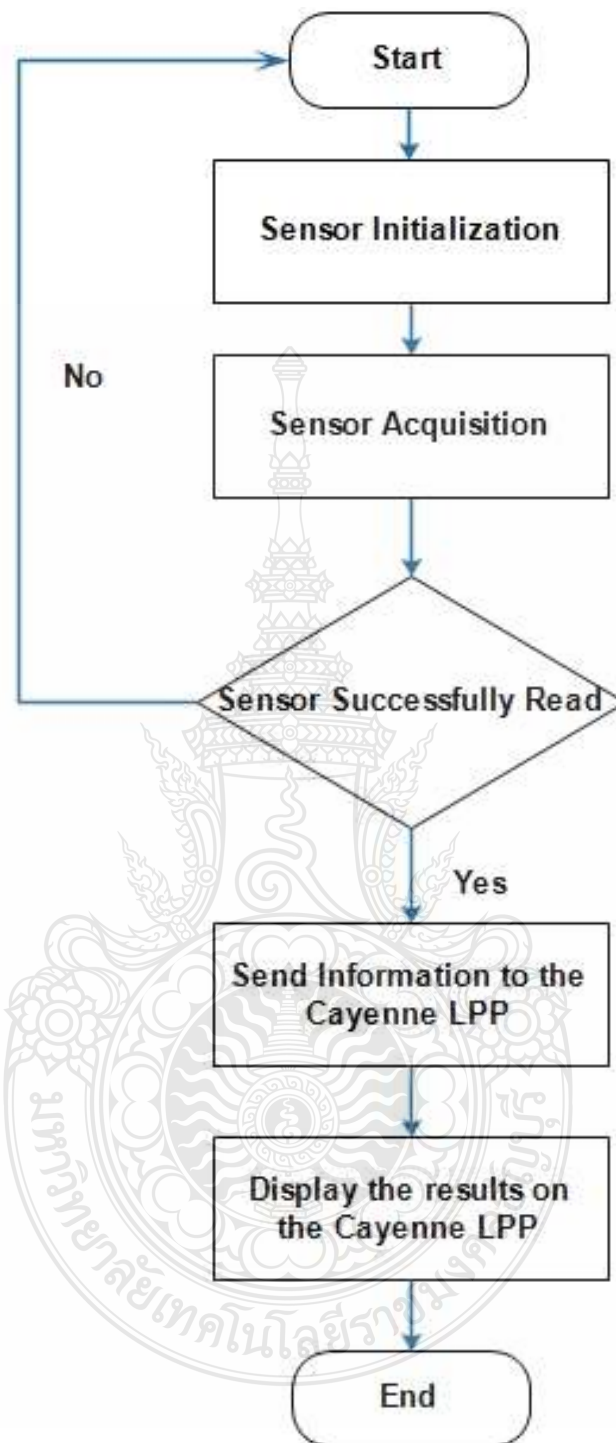


Figure 3.12 Flow chart of the system

3.3 Web Portal

Web Portal is an Internet of Things (IoT) device management system and application endpoints (Application Server) that users may set up on demand so that the device can connect and send information from the device's source of application direction. It has the following primary functions such as routing profile, device management, connectivity, logger, and downlink.



Figure 3.13 Web Portal of CAT LoRa IoT Platform

3.3.1 Access the system.

After entering their username and password, the administrator chooses the login button. The user can confirm the password's correctness by pressing the button.

The image shows a login interface for CAT. At the top center is the 'CAT' logo. Below it are two input fields: 'Username' containing 'bewbew12' and 'Password' containing masked characters. An orange 'Login' button is positioned below the password field. Underneath the button are two links: 'Not a member? Sign Up' and 'Forgot Password?'. At the bottom of the form, there is a footer with the text '© 2022, LoRa IoT by CAT TELECOM'.

Figure 3.14 Login Form

3.3.2 Sing Up

The subscriber is the user of the LoRa IoT by CAT service who has the authority to join the device to the LoRa IoT by CAT (Connectivity) network and is responsible for the devices linked to the network, including the data sent between the devices and the network. A natural person or a legal person, a department shop, a corporation, or an organization may be the user. User Account refers to an account used by an individual to access the LoRa IoT by CAT portal system and execute different device-related operations, as well as the right to connect to the user's device when applying as a service user. You may also create extra user accounts to be an account that can control various aspects of the service user's information. To share device management services and Connect rights with service users. The following stages comprise the registration procedure.

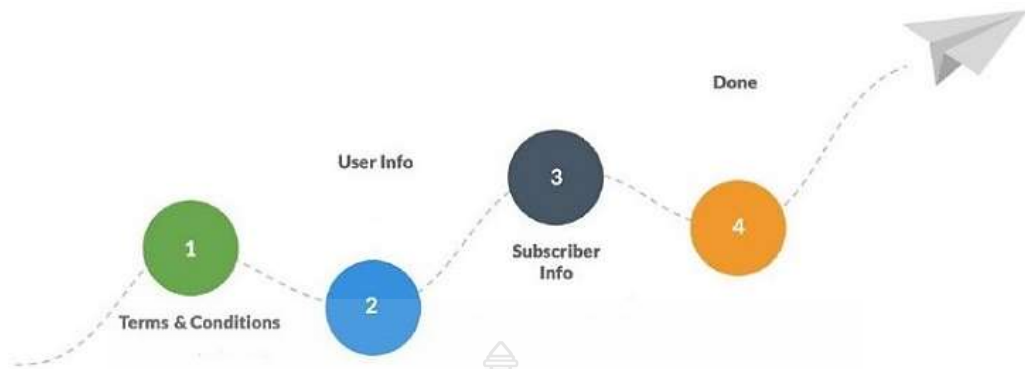


Figure 3.15 Registration Process (Sing Up)

Users must carefully read and comprehend the terms and restrictions of the LoRa IoT service. All users who fulfill the approval requirements of such agreements must postpone their reading until they can complete it. Tick the "First Box" and "Settings" boxes, then ask the user to click the "Next" button.



Figure 3.16 Terms and Conditions

The user accurately and thoroughly fills up the user account credentials. Then, click the next button to begin the user information procedure.

Register

1 Terms & Conditions —
 2 User Info —
 3 Subscriber Info —
 4 Done

1 Please enter the following information about the account owner.

* Firstname <input type="text" value="Enter your first name"/>	* Lastname <input type="text" value="Enter your last name"/>
* Email address <input type="text" value="Enter your email"/>	
* Username <input type="text" value="Enter your username"/>	
* Password <input type="password" value="Enter your password"/>	* Confirm Password <input type="password" value="Enter your confirm password"/>

Next

© 2019, LoRa IoT by CAT TELECOM

Figure 3.17 User Information

Users can fill out service user details in two ways: corporate information, company or organization (Corporate), and natural persons (Individual) and a 13-digit taxpayer identification number (Tax ID), but if the user chooses to fill out the information as Individual, the user must fill out the 13-digit identification card number (Citizen ID) and the system will automatically enter the name-surname in the Name field when the details are filled out. To register, the user must authenticate their identity by ticking and pressing the register button. The user can return to the User Info page by using the back button.

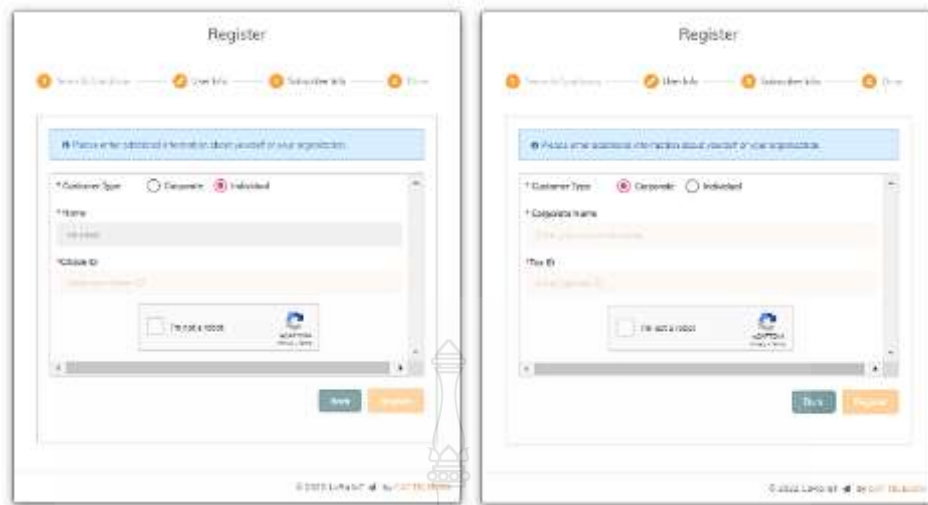


Figure 3.18 Subscribe Info

After successful registration, the system will send a registration confirmation email. Before being able to access the Web Portal, the user must successfully authenticate his or her account to confirm the subscription to use the service.



Figure 3.19 The registration is completed (Done)

3.3.3 Routing Profile

Is a menu that allows you to create, change, and delete connection profiles (Routing Profiles) as well as the receiving destination (Endpoint URL). When adding more than one device, the connection profile name (Routing Profile) is utilized. The user navigates to the Routing Profile menu and then clicks the Add Routing Profile button to begin the process of establishing a new connection profile. The system will display the Routing Profile screen, where users may enter the name of the pro (Routing Profile Name). Fill in the information as needed and hit the “Yes” button to confirm and click the button “No” to cancel.

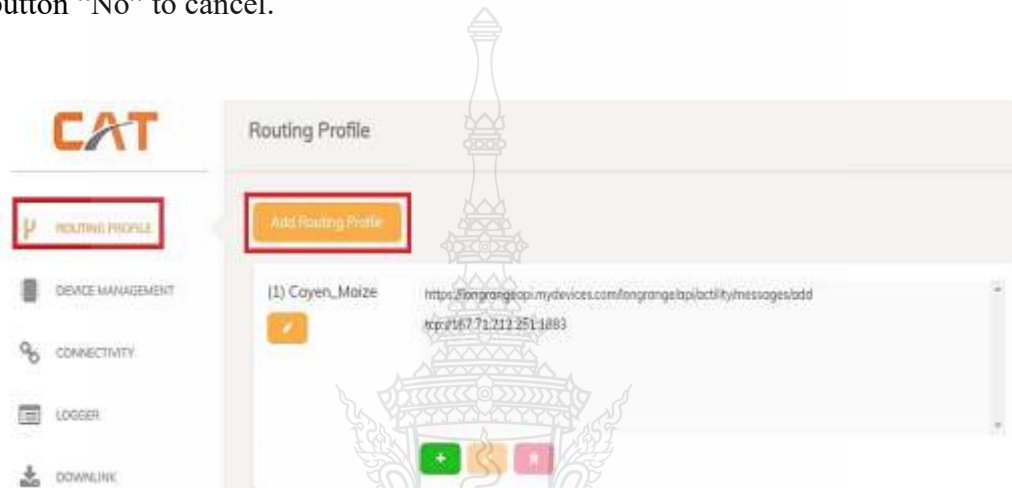


Figure 3.20 Add New Routing profile.

When the user wishes to replace or amend the connection profile name (Input the specific name of your project), the user may do so by pressing the button placed under Routing Profile Name. When such information is edited, the system will display the Edit Routing Profile screen. Allow the user to confirm by pressing the “Yes” button or cancel by using the “No” button.



Figure 3.21 Edit Routing Profile

The user may set a data-receiving destination or Endpoint Uniform Resource Locator (URL) to each Routing Profile by heading to the Routing Profile that needs the Endpoint URL and pressing the (+) button. The Add Endpoint URL page will be shown by the system. The user can enter data. Both Hypertext Transfer Protocol and MQ Telemetry Transport are supported. Users can only add up to ten Endpoint URLs to each Routing Profile.

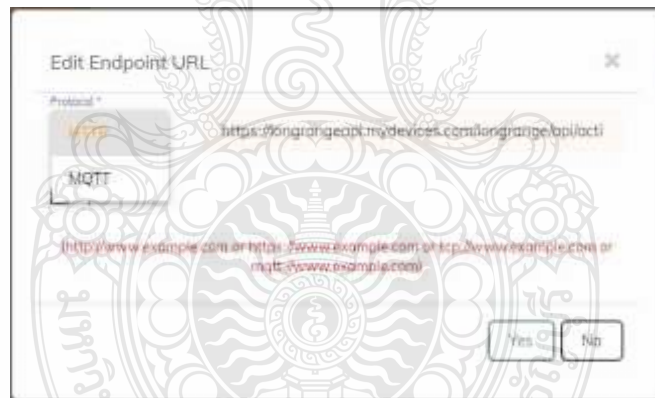


Figure 3.22 The Web Portal supports both HTTP and MQTT transmission protocols.

HTTP contains a URL from which the user can enter the URL in the form <https://longrangeapi.mydevices.com/longrange/api/actility/messages/add> users can also specify the Endpoint Guard by selecting the options tick and filling in Details of Basic Authentication, which consists of Username and Password. When the user has finished filling out the specifics of such information, hit the Yes button to confirm or the No button to cancel.



Figure 3.23 Web Portal HTTP Protocol

3.3.4 Device Management

If there are no connectivity instances, then select the add device or add multiple device button. The warning "this account does not have connectivity instances" will be shown. The user will not be able to create. This is because users must have connectivity instances to connect devices to the system.



Figure 3.24 Add Devices Management

Press the add devices button if the user only wishes to add one device at a time. Fill in the device's data based on the kind of Activation Mode, which includes OTAA and ABP. After that, the user must fill in the data accurately and thoroughly following the rules of each Activation Mode. Then, to confirm, click the "Yes" button, or to cancel, press the "No" button.

The screenshot shows a web form titled "Edit Device" with the following fields and values:

- Name: Project_3
- Activation Type: ABP (highlighted with a red box)
- Device EUI: FF1721AC76217101
- Device Address: 76217101
- Network Session Key: 2BAED22B7E1516A609CFABF715884F3C
- Application Session Key: 1628AE2B7E15D2A6ABF7CF4F3C158809
- Payload Format: Cayenne LPP
- Routing Profile: IoT Based Water Quality Monitoring System Using LoRaWAN
- Device Profiles: LoRaWAN 1.0.2 Class A - AS923 - Generic
- Connectivity Instances: Starter-kit | 1 / 1 | Exp. 06/07/2023

At the bottom right of the form, there are two buttons: "Yes" and "No".

Figure 3.25 Active Mode ABP

3.4 Cayenne LPP Cloud Computing

Application servers are referred to as "Internet of Things (IoT) network endpoints" since they accept data from IoT devices or values from various sensors. transmission across the network and bringing the findings to the user for the user to be aware of the various data values The Application Server provides a wide range of capabilities such as data storage based on user needs, data analysis, and data processing from various devices. or showing data in graph form; sometimes called a dashboard, and can be further developed as a Web Application, Mobile Application, and Cloud Application, among other things.

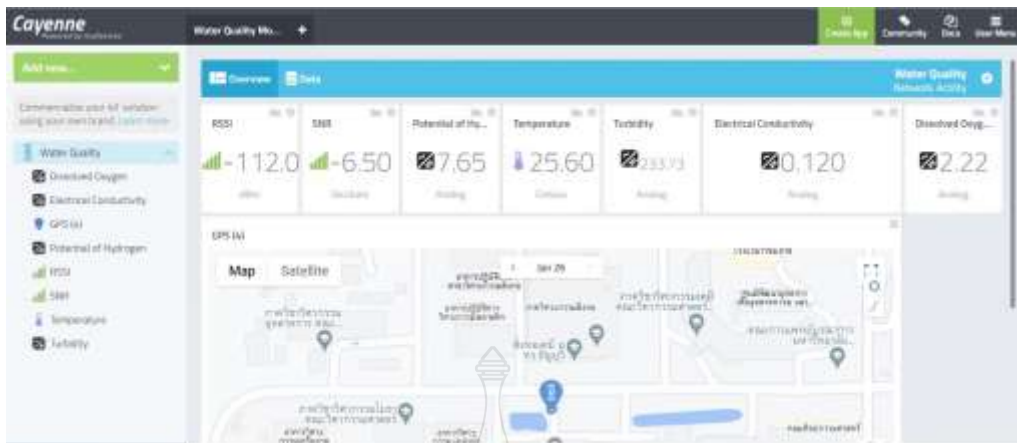


Figure 3.26 Cayenne LPP Dashboard

3.4.1 Register

You can browse to “<https://developers.mydevices.com/cayenne/features/>” and then click sign up free. A screen will appear where the user can provide some information for criteria and then click the register button.

The screenshot shows a registration form titled 'Register'. The form includes the following fields:

- First name
- Last name
- Email
- Password
- Confirm password

At the bottom of the form, there is a blue button labeled 'Register' and a link that says '+ Back to Login'.

Figure 3.27 Registration Form

3.4.2 Setup Cayenne LPP

After logging in to the Cayenne platform, you must choose a device to begin a project. LoRa is the device of choice.

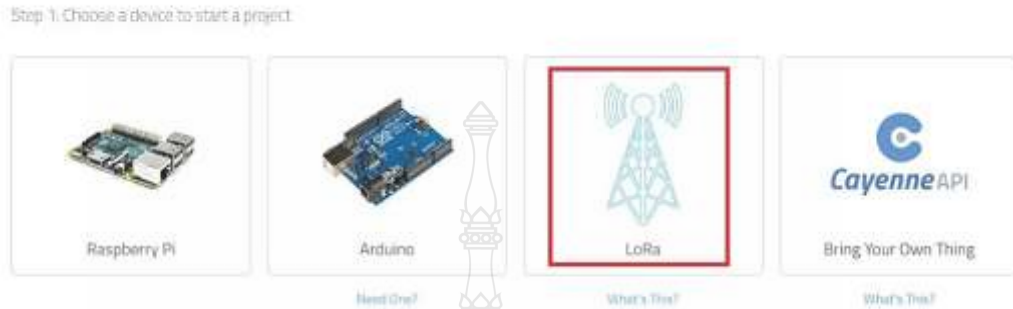



Figure 3.28 Choose a device to start a project.

Enter Settings

 Cayenne Cayenne LPP
Cayenne Low Power Payload

This device uses Cayenne LPP

Name
Cayenne LPP

Device ID
FF1721AC76217101

Registration Mode
Already Registered

ThingPark Server

ThingPark Email

ThingPark Password

Tracking

Location
This device moves

Add device

Figure 3.29 Add Device EUI

We can select the device model, Cayenne LPP in this project. Cayenne LPP was selected for this guide to add your device, you must give it a name (FF1721AC76217101) and verify its DevEUI. Because this instruction assumes your end device is already linked to the things Stack, choose Already Registered for the Activation Mode. What you select under tracking location is determined by the model of your device, namely whether it can send location coordinates or not. If you choose This device doesn't move, you must give a static location for your device and then click add devices to finish.



CHAPTER 4 RESEARCH RESULT

In this chapter, we will discuss the processing and results of the sensor view as a graph on the cloud based on IoT and LoRaWAN to monitor water quality through the internet to transfer information to the server station and then could therefore illustrate any parameters together with turbidity, the potential of hydrogen (pH), temperature, electrical conductivity (EC), dissolved oxygen (DO) and global positioning system destinations when utilizing Long Range (LoRa) to transmit messages across long distances.

4.1 Performance of Experimental



Figure 4.1 Measuring Parameter of Water Quality

Water quality monitoring system measurements were made over the LoRaWAN network to measure water quality and controlling value on cloud computing in front of the Department of Electronics and Telecommunications Engineering (ETE), and secondly, results were presented on the web. Furthermore, table 4.1 to table 4.5 shows the measuring results of sensors such as pH, temperature, electrical conductivity, turbidity, and dissolved oxygen collaboration using measuring compare with standard tool and the percentage of each sensor less than 5%.

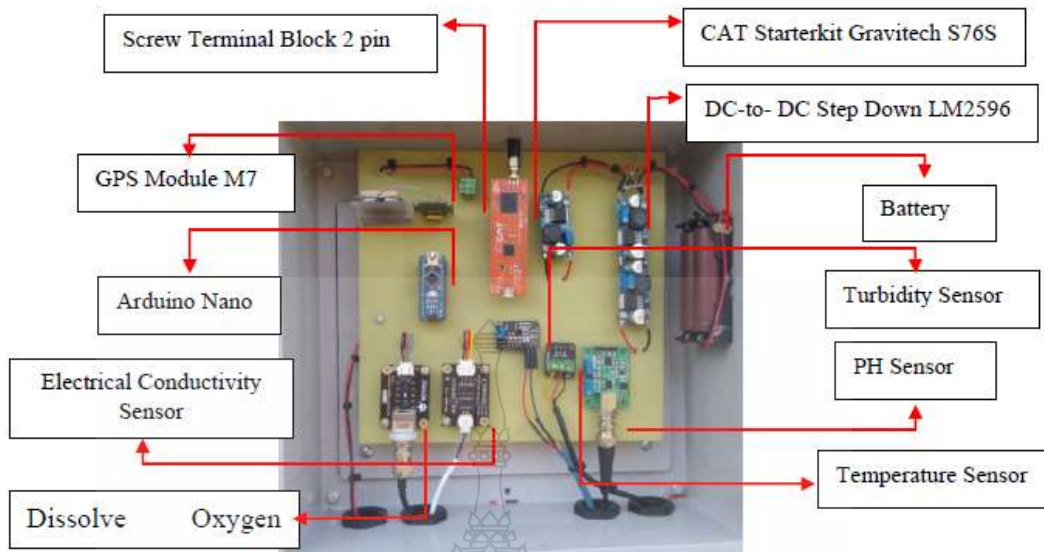


Figure 4.2 Details inside the box

Figure 4.2 above describes details of all of the devices inside the box clearly how to install every device in every port with a microcontroller and every sensor design internally so that users can measure and control the water quality monitoring system using the LoRaWAN network and store data in the cloud. The devices that can be installed are the GPS Module, DC-to-DC Step Down LM2596, CAT Starterkit Gravitech S76S board, LG 18650 HG2 3000mAh 20A lithium battery, Arduino Nano board, the potential of hydrogen sensor, temperature sensor, electrical conductivity sensor, turbidity sensor, and dissolved oxygen sensor, all of which are connected to screw terminal block that has 5 voltages for operation whole system.

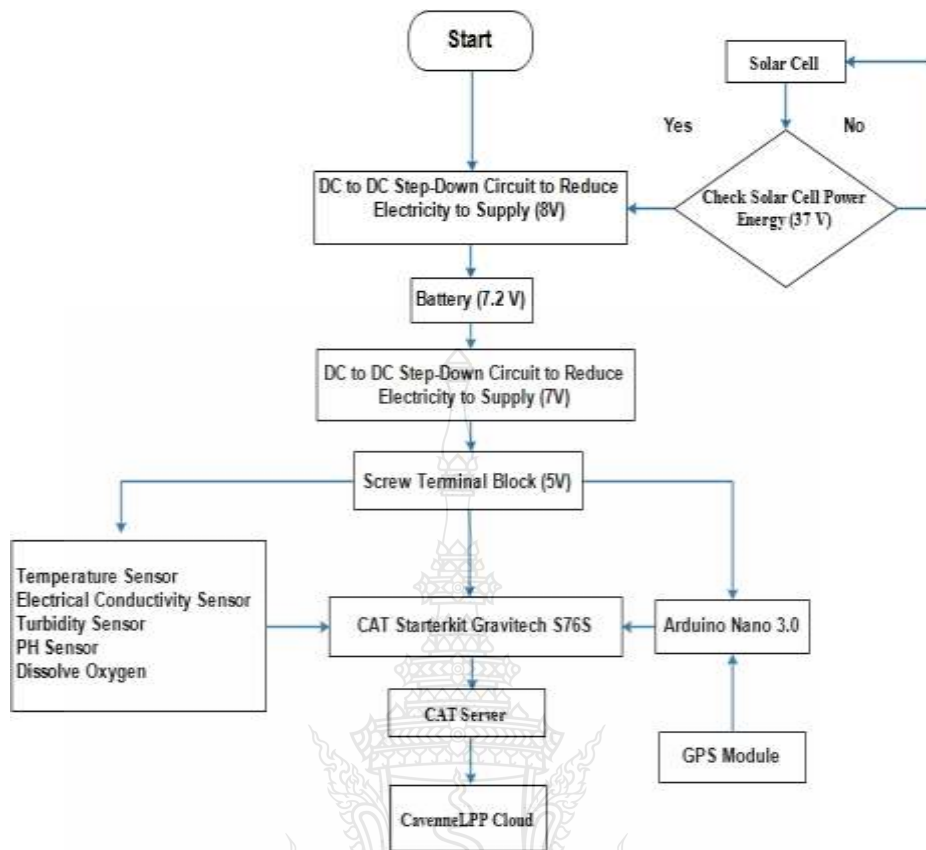


Figure 4.3 Flow chart system of experimental

Based on Figure 4. 3 following the completion of the hardware and software (code) installation, this step will explain how to process an experiment to obtain data for discussion and analysis. In addition, the first time our system is put into operation, we must ensure that the primary power supply for the solar cells is going to convert energy into electric energy with a control box to device power supply for the entire operation. The first Dc to DC step-down plays a crucial role in reducing the amount of electricity supplied to the circuit, followed by the battery to save the power operation system at night when the solar cell is not receiving any power. A second Dc to DC step-down circuit is also included to further reduce electricity. Particularly all sensor, GPS, and tow microcontrollers are connected via screw terminal blocks, such as the Arduino Nano and CAT Starterkit Gravitech S76S. In the end, all sensor and GPS location data will be displayed on the CAT server, and Cayenne Low Power Payload (CayenneLPP) will download the data and display it on the dashboard in three different line charts, value, and gauge formats.

Figure 4.4 Login Form

Before viewing and downloading data and information on the cloud server of Cayenne LPP, the user must have a username and password to login in to access it. This is the link to access it <https://cayenne.mydevices.com/cayenne/dashboard/first-visit/devices> after clicking the link it will display a form to input your email in this section we use (va.savel@moeys.gov.kh) and then complete with password (*777888@ADMINS168) click the button “Log In” to finish your process.

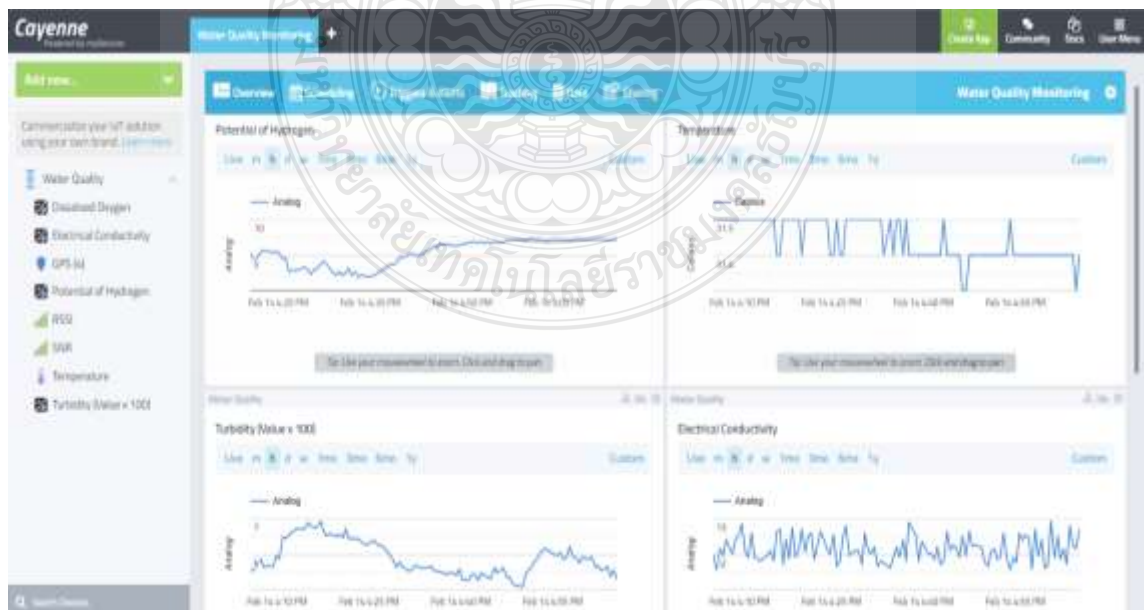


Figure 4.5 View value on the Cayenne LPP

Illustrates 4.5 show, the acquired data is kept in real-time data, last 10 minutes, last 60 minutes, last 24 hours, last 7 days, last 30 days, last 3 months, last 6 months, last 12 months, and custom user can choose different time by yourself and substantial on the cloud computing system and always contains a parameter of sensor such temperature, conductivity, turbidity, the potential of hydrogen (pH), dissolved oxygen sensor (DO), and location measurements derived from four sensors and global positioning system receiver.

4.2 Real-Time Monitoring System and Test Result

The table below shows data from five sensors after measuring experiments using IoT and LoRaWAN to the monitoring system of water parameters. According to the result of the experimental to compute the percentage of mistakes (%), sensor we can apply the formula below:

$$\text{Error (\%)} = \frac{\text{Standard Tool} - \text{Measured Value}}{\text{Standard Tool}} \times 100 \quad (4.1)$$

Table 4.1 Testing Parameter of the temperature sensor.

Temperature (°C)		
Testing	Standard Tool	Value of Measuring
1	28.2	28.1
2	28.3	28.2
3	28.2	28.1
4	28.3	28.3
5	28.3	28.2
6	28.4	28.4
7	28.3	28.1
8	28.2	28.2
9	28.2	28.1
10	28.3	28.1

$$\text{Error (\%)} = \frac{28.27 - 28.18}{29.656} \times 100 = 0.31 \% \quad (4.2)$$

Temperature Sensor: The Circuit receives analog voltage measurements because of the water-resistant temperature sensor, allowing communication straightforward. Temperatures can be measured from 0 to 100 degrees Celsius. The chemical reaction is catalyzed by water temperature, which reduces the amount of dissolved oxygen. The temperature of the water ranged from 23 to 32 °C, and even the research findings for a mean difference that was lower than, the percentage difference technique was used. zone point five (0.5%) percentage.



Figure 4.6 Measurement of Temperature Sensor

Figure 4.6 demonstrates how a sensor measures water temperature in the -50 to 125 degrees Celsius range. According to its temperature, water is generally divided into three categories: cold, normal, and hot. Cold water is defined as having a temperature between -55 to 20 degrees Celsius, normal water is defined as having a temperature between 21 to 39 degrees Celsius, and hot water is defined as having a temperature between 40 to 125 degrees Celsius.

Table 4.2 Testing Parameter of electrical conductivity sensor.

Electrical conductivity (ms/cm)		
Testing	Standard Tool	Value of Measuring
1	14.87	14.79
2	15.05	14.99
3	15.22	15.18
4	14.65	14.50
5	14.72	14.64
6	14.63	14.59
7	14.49	14.45
8	15.12	15.03
9	14.29	14.20
10	15.14	14.94

$$\text{Error (\%)} = \frac{14.818 - 14.731}{14.818} \times 100 = 0.58 \% \quad (4.3)$$

Electrical Conductivity: the amount of liquid inorganic substances measured with this approach determines the water transport capacity. Distilled water has a conductivity that ranges between 0.5 and 3 mhos/cm. River fisheries benefit from conductivity values ranging from 150 to 500 mhos/cm. However, many animals and large aquatic animals cannot live at greater conductivity levels. The conductivity of ground and surface waters is 10,000 mhos per centimeter, and the findings were computed using a proportion of total difference mathematical model with a sampling error compared with fewer than two (2%) percent.



Figure 4.7 Measurement of Electrical Conductivity Sensor

Results for conductivity for freshwater are shown in Figure 4.7 in the appropriate order. The electrical conductivity is within the acceptable range for good water quality, according to these results. A measure of the water's electrical conductivity is called conductivity. Conductivity levels should be between 0 and 2500 $\mu\text{S}/\text{cm}$, as was already mentioned. The number of ions that are dissolved in the water affects conductivity. A good conductor of electricity is therefore water of high quality.

Table 4.3 Testing Parameter of Potential of Hydrogen Sensor

Potential of Hydrogen		
Testing	Standard Tool	Value of Measuring
1	8.63	8.61
2	8.60	8.50

Table 4.3 Testing Parameter of Potential of Hydrogen Sensor (Continued)

Potential of Hydrogen		
Testing	Standard Tool	Value of Measuring
3	15.22	15.18
4	14.65	14.50
5	14.72	14.64
6	14.63	14.59
7	14.49	14.45
8	15.12	15.03
9	14.29	14.20
10	15.14	14.94

$$\text{Error (\%)} = \frac{8.576 - 8.478}{8.576} \times 100 = 1.14 \% \quad (4.4)$$

pH Sensor: The Microcontrollers Input pH Sensor is a simple sensor which thus uses Arduino's Analog dc output voltage to determine the concentration of hydrogen ions. The pH was varied from zone to fourteen 0 – 14, and the outcomes have been derived using the percent difference cost-benefit analysis for a percentage difference that was less than five (5%) percent.



Figure 4.8 Measurement of the potential of hydrogen Sensor

The sensor used to measure the water's potential of hydrogen, which ranges from 0 to 14, is shown in figure 4.8. Water is divided into acid, normal, and base categories based on its potential hydrogen value. A value of less than 7 is regarded as an acid, a value of more than 7 as the base, and a value of 7 as typical or good water. It is

again divided into two categories in acid low acid (3 to 6) and high acid (0 to 2). The classification of base water into two types is a low base (8 to 10) and a high base (11 to 14).

Table 4.4 Testing Parameter of Turbidity Sensor

Turbidity sensor (NTU)		
Testing	Standard Tool	Value of Measuring
1	3001	3000
2	3003	3000
3	3002	3000
4	3005	3000
5	3004	3000
6	3007	3000
7	3009	3000
8	3003	3000
9	3000	3000
10	3000	3000

$$\text{Error (\%)} = \frac{3003.4 - 3000}{3000} \times 100 = 0.11 \% \quad (4.5)$$

Turbidity sensor: The degree of water turbidity is determined by measuring conductivity and light refraction. It operates at +5v power supply and produces an analog voltage ranging from (0.4- 5V) as well as a digital high or low by adjusting the value of the height adjustment voltage divider, with the values obtained with a percentage error of lower than five (5%) percent using the standard deviation computation.



Figure 4.9 Measurement of Turbidity Sensor

The clarity of the water is determined by its turbidity. If any sand, mud, sand, or silt is present, the quality of the water will change. According to water quality standards, normal water ranges from 0 to 5 NTU (Nephelometric Turbidity Units), though it can still exceed 5 NTU. In the range of 6 NTU to 3000 NTU, water is categorized as turbid or mixed with mud. The water turbidity measurement is shown in Figure 4.9.

Table 4.5 Testing Parameter of Dissolve Oxygen Sensor

Dissolve Oxygen Sensor (mg/L)		
Testing	Standard Tool	Value of Measuring
1	9.59	9.57
2	9.39	9.27
3	9.13	9.11
4	9.31	9.29
5	9.1	9.12
6	9.23	9.13
7	9.17	9.15
8	9.13	9.12
9	9.18	9.46
10	9.22	9.15

$$\text{Error (\%)} = \frac{9.245 - 9.237}{9.245} \times 100 = 0.08 \% \quad (4.6)$$

Dissolved oxygen: The voltage and the amount of dissolved oxygen are inversely related when the temperature is constant. Before precise data can be obtained, the calibration of the voltage corresponding to the saturated dissolved oxygen is required due to the minor variations in the probe's production. Temperature changes have a significant impact on dissolved oxygen that is saturated. It is necessary to consider changes in dissolved oxygen and saturation voltage brought on by temperature changes to increase accuracy. The following graph depicts the general relationship between temperature and saturation voltage. To create a temperature compensation curve, the saturated dissolved oxygen voltage must be measured at two different temperatures. Since the relationship between temperature and saturated dissolved oxygen at standard atmospheric pressure is known, measuring the temperature, and calculating the dissolved oxygen will yield the saturated oxygen concentration and corresponding voltage at the current temperature and using the standard deviation calculation, with a percent error of less than five (0.5%) percent.



Figure 4.10 Measurement of Dissolve Oxygen Sensor

The amount of non-compound oxygen that is mixed with water is measured as dissolved oxygen (DO). It is a crucial factor in figuring out the water's quality. A dissolved oxygen level that is either too high or too low can harm aquatic life and reduce water quality. Reduced levels of dissolved oxygen are a result of high levels of turbidity, rising water temperatures, and salinity. The temperature of the water body is the factor that has the greatest impact on dissolved oxygen content. In milligrams per liter (mg/L), the dissolved oxygen level is specified. The ideal range for dissolved oxygen is 7.3 to 9.5 (mg/L).



Figure 4.11 Measurement of RSSI

The received signal strength indication (RSSI) is the received signal power in milliwatts and is measured in dBm. This value can be used as a measurement of how well a receiver can hear a signal from a sender. The RSSI is measured in dBm and is a negative value. The closer to zero the better the signal is. Typical LoRa RSSI values are RSSI

minimum equal (-120 dBm) if our RSSI value is equal minus (-30 dBm) the signal is strong and if our RSSI value is equal minus (-120 dBm) the signal is weak. This graph in Figure 4.8 below shows that our RSSI value around minus around (-114 to -119 dBm) is mean that signal in front of the department of electronics and telecommunication engineering is weak.

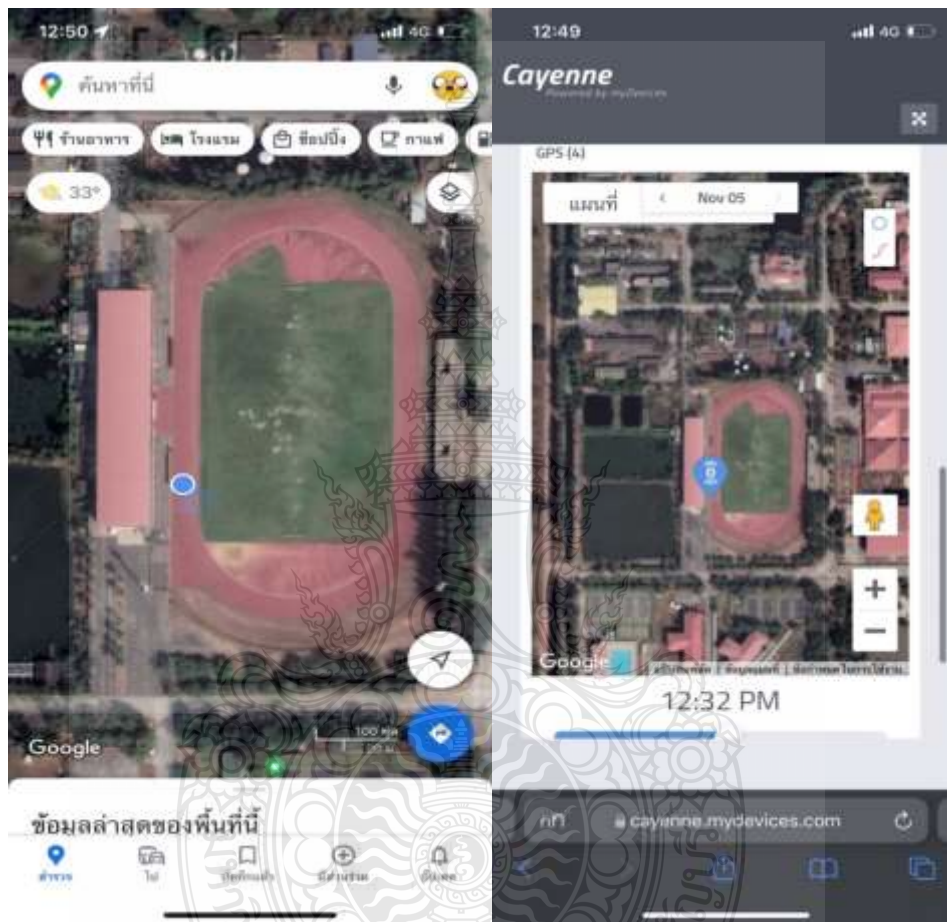


Figure 4.12 GPS Location Central Stadium RMUTT

The Central Stadium RMUTT location is shown in Figure 4.12 with additional information. According to the global positioning system, this location's latitude and longitude are 14.0347697 and 100.7226127 on Google Maps, while Cayenne LPP's latitude and longitude are 14.0376 and 100.7226 for this location.

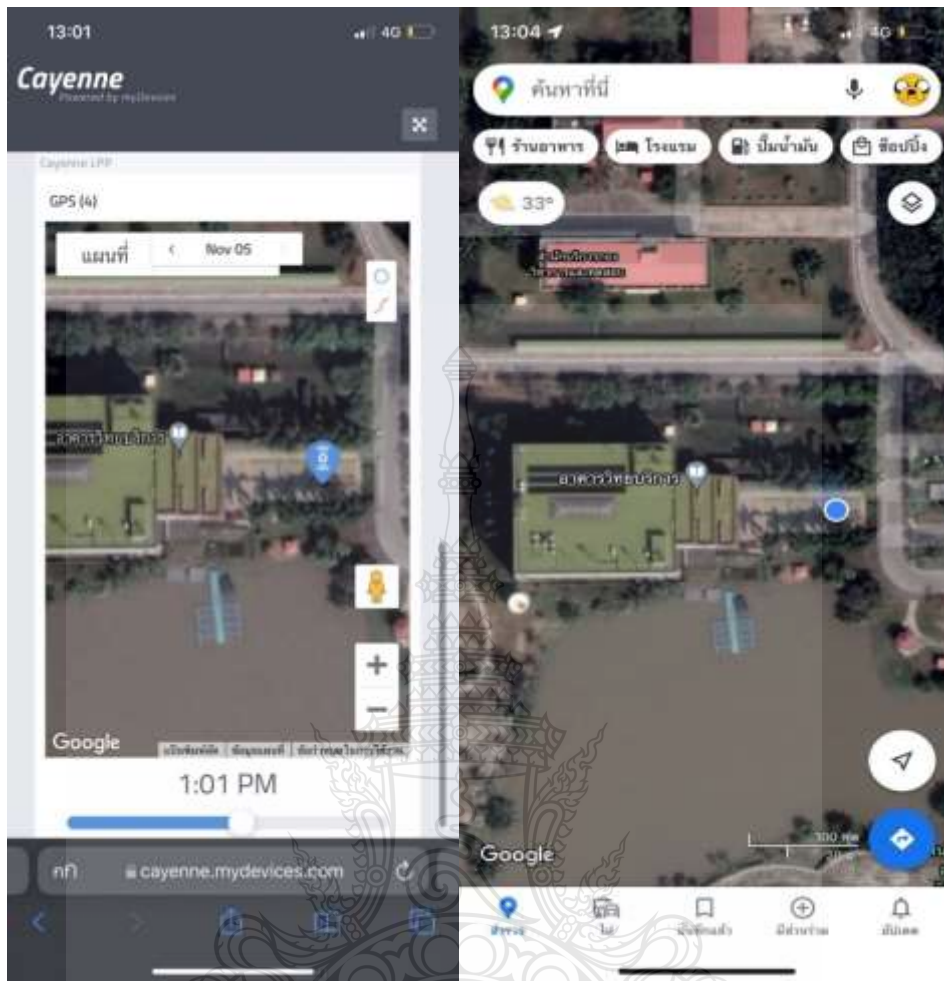


Figure 4.13 GPS Location RMUTT Central Building

On Google Map, the Academic Building (Central Library) is shown with the latitude and longitude of 14.034206 and 100.726035, which are between the GPS longitude and latitude for the Cayenne low power payload (Cayenne LPP), which are 14.0342 and 100.7260.

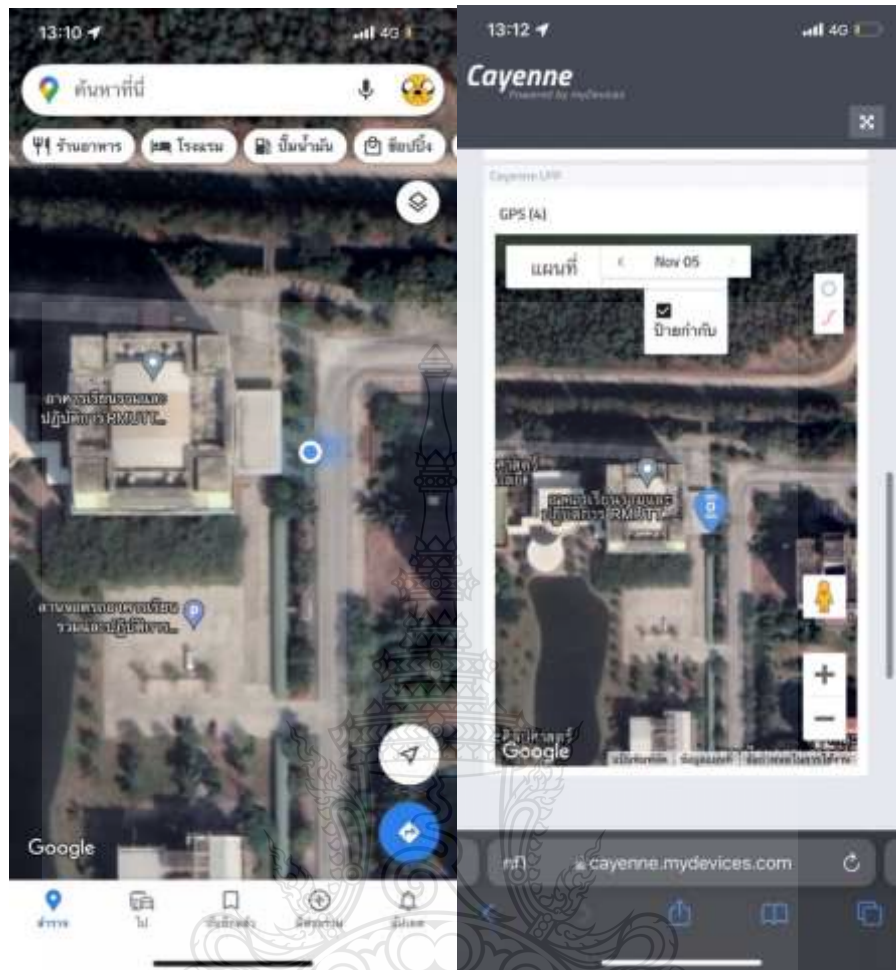


Figure 4.14 GPS Location Central Library

Figure 4.14 includes location information. On Google Maps, an integrated learning and operating building with the coordinates 14.039535 and 100.730237 is marked as being at latitude 14 and longitude 100.730237, respectively. These coordinates are roughly the same as the GPS coordinates for Cayenne LPP, which are 14.0395 and 100.7302.

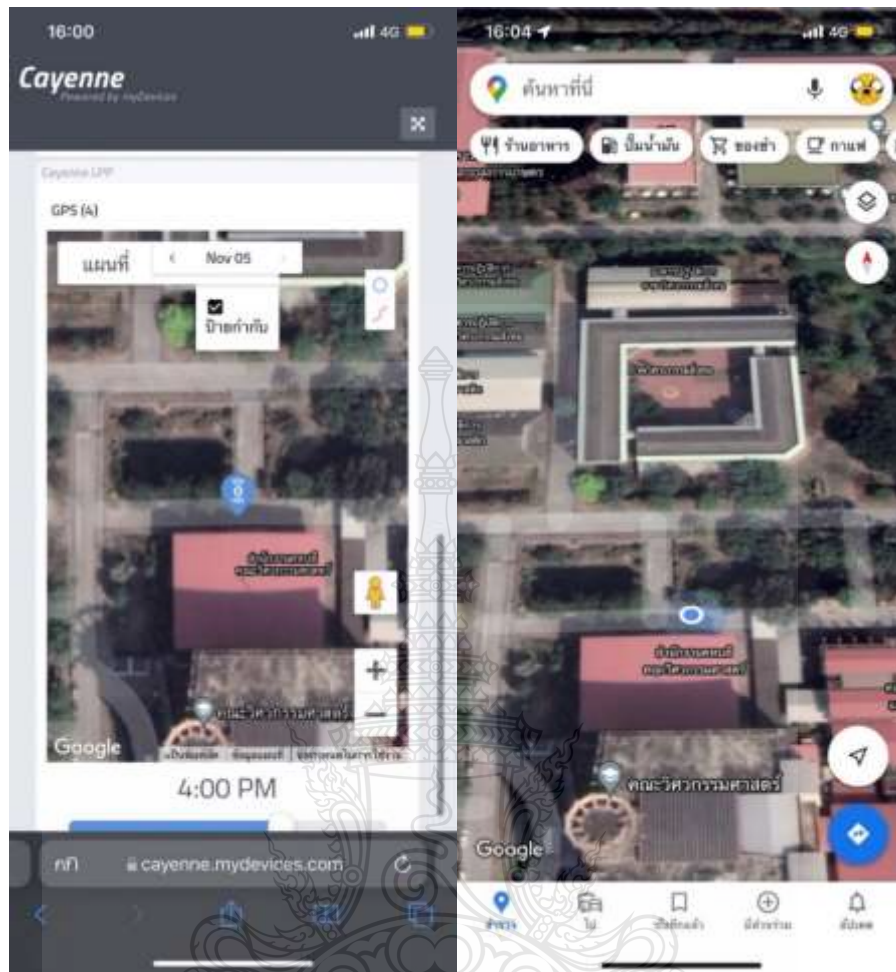


Figure 4.15 GPS Location in front of the department of ETE

The location-specific data in Figure 4.15 is shown in front of the electronics and telecommunication engineering department at the Rajamangala University of Technology Thanyaburi. The department's latitude and longitude are 14.037526 and 100.726125 on Google Maps, which is also the GPS longitude and latitude for Cayenne LPP, which are 14.0375 and 100.7261.



Figure 4.16 GPS Location in the Different Place view on Google Map

The water quality monitoring system uses long-range wide area network (LoRaWAN) communication to measure, and display the GPS position in Google Maps and the cloud Cayenne LPP to define the latitude value and the longitude value in four different locations around the university, including Central Stadium, Academic Building (Central Library), Integrated Learning and Operating Building, and in front of the department of electronics and Telecommunication Engineering at the Rajamangala University of Technology Thanyaburi.

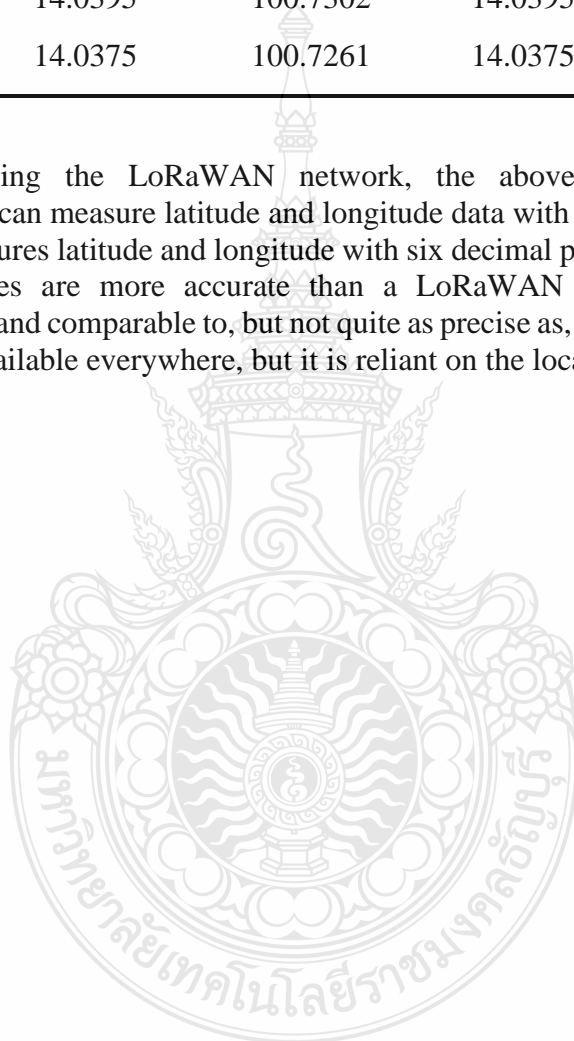
Table 4.6 Testing Parameters of GPS

GPS Experiment Research results				
Testing	Cayenne LPP		Google Map	
	Latitude	Longitude	Latitude	Longitude
1	14.0376	100.7226	14.0347697	100.7226127

Table 4.6 Testing Parameters of GPS (Continued)

GPS Experiment Research results				
Testing	Cayenne LPP		Google Map	
	Latitude	Longitude	Latitude	Longitude
2	14.0342	100.7260	14.034206	100.726035
3	14.0395	100.7302	14.039535	100.730237
4	14.0375	100.7261	14.037526	100.726125

When using the LoRaWAN network, the above-ground water quality monitoring system can measure latitude and longitude data with four decimal places, but Google Maps measures latitude and longitude with six decimal places. The readings with four decimal places are more accurate than a LoRaWAN network water quality monitoring system and comparable to, but not quite as precise as, Google Maps. Use CAT signal service is available everywhere, but it is reliant on the local weather.



CHAPTER 5

CONCLUSION AND FUTURE WORK

Chapter 5 has two sections made up. This study has a conclusion, and an explanation of the test results is provided in section 5.1. The final section contains the researcher's suggestions for additional research on this study.

4.3 Conclusion

The goal of this research is to create an internet of things based on a water quality monitoring system in real-time that can display parameters of pH, turbidity, temperature, electrical conductivity, dissolved oxygen, and GPS locations on cloud computing in this section we use CAT server and then transfer to Cayenne LPP dashboard while transmitting data over a one-kilometer distance using solar power and the Long-Range Wide Area Network (LoRaWAN). The experiment shows that the battery system can run for more than 36 hours without charging a solar panel. Additionally, the water quality monitoring system experimentally determined that the Potential of Hydrogen value 8.47 is mean that this water contains a low base, turbidity of 3000 Nephelometric Turbidity Units (NTU), which classifies water as turbid or mixed with mud, temperature of 28.18 degrees Celsius (°C), which is defined as having normal water, for good water quality, the electrical conductivity is within the acceptable levels 14.73 $\mu\text{S}/\text{cm}$ as was previously mentioned, dissolved oxygen is 9.23 milligrams per liter (mg/l) is good oxygen in the water and percentage error is less than 5 %.

4.4 Future Work

There are numerous others, and if you can apply all these theories or pieces of knowledge to further study or development, it might be useful in the future—for example, in wastewater treatment systems. By controlling and making more good oxygen in the water we are recommended to put the propeller working every time, fishponds for a variety of households can be used to increase the oxygen content of the water for aquatic life. To be more effective for the simplicity of remote monitoring via the LoRaWAN network, additional advancements are acceptable for everyone interested in bringing water quality monitoring systems via the LoRaWAN network. The proposed system will eventually be fully developed and tested, with Arduino-based Internet of Things (IoT) LoRaWAN sensors and a Raspberry Pi acting as the gateway.

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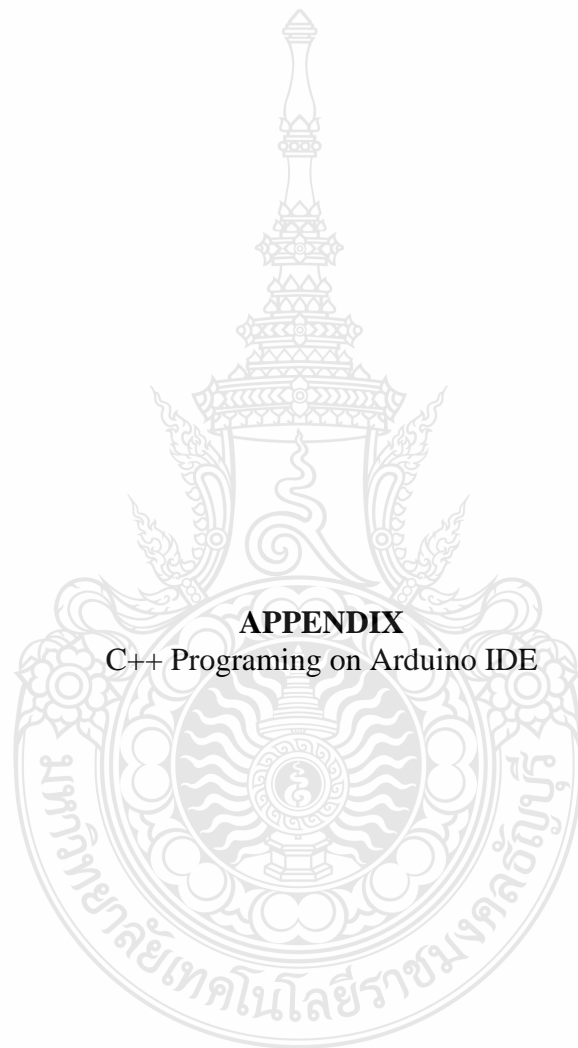
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APPENDIX

C++ Programming on Arduino IDE

```

#include "catLoRa.h" //Calling the cat library
#include <CayenneLPP.h> //Running the cyenneLPP library
#include <OneWire.h>
#include <DallasTemperature.h> //Calling the temperature library
#include <Wire.h> // I2C
#include <Arduino.h>

#define ONE_WIRE_BUS A1

String buff;
String _lat, _lng;

#define SensorPin A0 //pH meter Analog output to Arduino Analog Input 0
#define Offset 0.00 //deviation compensate
unsigned long int avgValue; //Store the average value of the sensor feedback

int sensorPin = A2;
float volt;
float ntuTb;

int buf1[10]; // //buffer for read analog.
int sensorValue = 0; //Set sensor variable
float voltageValue = 0; //Set voltage variable
catLoRa lora; //Run the command in the cat lora library.
CayenneLPP lpp(51);

String _CLASS = "A"; //Set class
String _devEUI = "FF1721AC76217118"; //Set devEUI
String _devADDR = "76217118"; //Set devADDR
String _port = "6"; //Set Port
String _payLoad = ""; //Create a string payload variable.

uint32_t Interval_Time_Old;
uint16_t Interval_Time;
OneWire oneWire(ONE_WIRE_BUS); //Run commands from one wire library.
DallasTemperature sensors(&oneWire);

#define EC_PIN A3
float voltage,ECValue,temperature = 25;

#define DO_PIN A4

#define VREF 5000 //VREF (mv)
#define ADC_RES 4096 //ADC Resolution

//Single-point calibration Mode=0

```

```

//Two-point calibration Mode=1
#define TWO_POINT_CALIBRATION 0

#define READ_TEMP (25) //Current water temperature °C, Or temperature sensor
function

//Single point calibration needs to be filled CAL1_V and CAL1_T
#define CAL1_V (1600) //mv
#define CAL1_T (25) //°C
//Two-point calibration needs to be filled CAL2_V and CAL2_T
//CAL1 High temperature point, CAL2 Low temperature point
#define CAL2_V (1300) //mv
#define CAL2_T (15) //°C

const uint16_t DO_Table[41] = {
    14460, 14220, 13820, 13440, 13090, 12740, 12420, 12110, 11810, 11530,
    11260, 11010, 10770, 10530, 10300, 10080, 9860, 9660, 9460, 9270,
    9080, 8900, 8730, 8570, 8410, 8250, 8110, 7960, 7820, 7690,
    7560, 7430, 7300, 7180, 7070, 6950, 6840, 6730, 6630, 6530, 6410};

uint8_t Temperature;
uint16_t ADC_Raw;
uint16_t ADC_Voltage;
uint16_t DO;

int16_t readDO(uint32_t voltage_mv, uint8_t temperature_c)
{
    #if TWO_POINT_CALIBRATION == 0
        uint16_t V_saturation = (uint32_t)CAL1_V + (uint32_t)35 * temperature_c -
        (uint32_t)CAL1_T * 35;
        return (voltage_mv * DO_Table[temperature_c] / V_saturation);
    #else
        uint16_t V_saturation = (int16_t)((int8_t)temperature_c - CAL2_T) *
        ((uint16_t)CAL1_V - CAL2_V) / ((uint8_t)CAL1_T - CAL2_T) + CAL2_V;
        return (voltage_mv * DO_Table[temperature_c] / V_saturation);
    #endif
}

String DO_value;

void setup() {
    // put your setup code here, to run once:
    Serial.begin(115200);
    pinMode(A0, INPUT);
    pinMode(A2, INPUT);
    pinMode(A3, INPUT);
}

```

```

pinMode(DO_PIN, INPUT);
analogReadResolution(12);
sensors.begin();
Interval_Time = 30000;
lora.begin(); //Getting started with Lora
lora.joinABP(_CLASS, _devEUI, _devADDR); //ABP connection
Wire.begin(6); //choose chanel 6
Wire.onReceive(receiveEvent); //Get value from I2C channel.
Serial.println("ready");

} //setup

void loop() {

lora.ledBLINK(); //Activating the LoRa LEDs
getPosition();
if (millis() - Interval_Time_Old >= Interval_Time) {
Interval_Time_Old = millis(); //Check the time of submitting the payload.

for(int i=0;i<10;i++) //Get 10 sample value from the sensor for smooth the value
{
buf1[i]=analogRead(SensorPin);
delay(10);
}
for(int i=0;i<9;i++) //sort the analog from small to large
{
for(int j=i+1;j<10;j++)
{
if(buf1[i]>buf1[j])
{
int temp=buf1[i];
buf1[i]=buf1[j];
buf1[j]=temp;
}
}
}
avgValue=0;
for(int i=2;i<8;i++) //take the average value of 6 center sample
avgValue+=buf1[i];
float pHValue = 1;
float pHValue1=(float)avgValue*5.0/4095/7.5; //convert the analog into millivolt
float pHValue2=3.5*pHValue1 + Offset;; //convert the millivolt into pH value
if (pHValue2 > 0){
pHValue = pHValue2;
}
}
}

```

```

}

sensors.requestTemperatures(); //Request a sensor temperature value with the library.
float Temp = sensors.getTempCByIndex(0); //Declare a Temp variable of type float.

float ntuTb = analogRead(A2); //Declare a sensorTb variable of type int.
volt = 0;
for(int i=0; i<800; i++)
{
    volt += ((float)analogRead(sensorPin)/1023)*5;
}
volt = volt/800;
if(volt < 2.5){
    ntuTb = 3000;
}else{
float ntuTb = -1120.4*(volt*volt)+5742.3*volt-4353.8;
}

float voltage = analogRead(EC_PIN)/1024.0*5000; // read the voltage
float ECValue = voltage/100 ;

Temperaturet = (uint8_t)READ_TEMP;
ADC_Raw = analogRead(DO_PIN);
ADC_Voltage = uint32_t(VREF) * ADC_Raw / ADC_RES;
DO_value = String(readDO(ADC_Voltage, Temperaturet));
float do_v = readDO(ADC_Voltage, Temperaturet);
Serial.println("DO:\t" + String(do_v/1000) + "\t");
Serial.println("pHValue =" + String(phValue));
Serial.println("temp =" + String(Temp));
Serial.println("ntuTb =" + String(ntuTb));
Serial.println("ECValue =" + String(ECValue));
Serial.println("lat = " + _lat + " | lng = " + _lng );

String d_alti = "004074" ;
String d_ph = getSensor(phValue);
String d_Temp = getSensor1(Temp);
String d_ntu = getSensor2(ntuTb);
String d_ec = getSensor3(ECValue);
String d_lat = getSensor4(_lat.toFloat());

```

```

String d_lng = getSensor5(_lng.toFloat());
String d_DO = getSensor6(DO_value.toFloat());

_payload = d_ph + d_Temp + d_ntu + d_ec + d_lat + d_lng + d_alti + d_DO; // Place
the cayennlpp brushed sensor values in the _payload variable.

if (lora.sendPayload(_port, _payload)) { //Set LoRa transmission conditions
  Serial.println("Start sending.....");
  Serial.println(d_ph);
  Serial.println(d_Temp);
  Serial.println(d_ntu);
  Serial.println(d_ec);
  Serial.println(d_DO);
  Serial.println(d_lat);
  Serial.println(d_lng);

  Serial.println(_payload); //Show payload value on Serial.monitor with conditions
  Serial.println("Send Payload OK");
}

Serial.println(".....");
delay(500);
}

void getPosition()
{
  int len = buff.length();

  if (len > 1)
  {

    _lat = getValue(buff, ',', 0);
    _lng = getValue(buff, ',', 1);
  }
  delay(100);
}

void receiveEvent(int howMany) {
  int i = 0 ;
  buff = "";

  while (Wire.available() > 0) { // loop through all but the last

```

```

char c = Wire.read();          // receive byte as a character

if (c == '"')
{
    break;
}
buff += c;

}

}

String getValue(String data, char separator, int index)
{
    int found = 0;
    int strIndex[] = { 0, -1 };
    int maxIndex = data.length() - 1;

    for (int i = 0; i <= maxIndex && found <= index; i++) {
        if (data.charAt(i) == separator || i == maxIndex) {
            found++;
            strIndex[0] = strIndex[1] + 1;
            strIndex[1] = (i == maxIndex) ? i + 1 : i;
        }
    }
    return found > index ? data.substring(strIndex[0], strIndex[1]) : "";
}

String getSensor(float pHValue) { //Create a condition for the string variable of pHValue.
    String ph = "";
    String cayenneLPPformat = "";
    String cayenph = "0002"; //0002 is the analog input of cayenlpp.
    ph = uint16_t(PHValue * 100); //Determine the storage of values at the pH variable.
    Serial.println(ph);
    char pHHex[5];
    sprintf(pHHex, "%04lx", pH.toInt()); //Converting decimal to hexadecimal
    Serial.print(cayenph);
    Serial.println(pHHex);
    cayenneLPPformat = cayenph + pHHex ; //Sort the cayenph and pHHex values into the
    cayenneLPPformat variable. of this condition
    Serial.print("cayenneLPPformat = ");
    Serial.println(cayenneLPPformat);
    return cayenneLPPformat; //Returns a value to a void loop.
}

String getSensor1(float Temp) { //Create a condition for a string variable of temp.

```



```

String temp = "";
String cayenneLPPformat = "";
String cayentemp = "0167"; //0167 is the temp input of cayennlpp
temp = uint16_t(Temp * 10);
Serial.println(temp);
char tempHex[5];
sprintf(tempHex, "%04lx", temp.toInt()); //Converting decimal to hexadecimal
Serial.print(cayentemp);
Serial.println(tempHex);
cayenneLPPformat = cayentemp + tempHex ; //Sort the cayentemp and tempHex values
into the cayenneLPPformat variable. of this condition
Serial.print("cayenneLPPformat = ");
Serial.println(cayenneLPPformat) ;
return cayenneLPPformat; //Returns a value to a void loop.
}

String getSensor2(float ntuTb) { //Create a condition of the string variable type of ntuTb.
String ntu = "";
String cayenneLPPformat = "";
String cayenntu = "0202"; //0202 is the analog input of cayennlpp.
ntu = uint16_t (ntuTb);
Serial.println(ntu);
char ntuHex[5];
sprintf(ntuHex, "%04lx", ntu.toInt()); //Converting decimal to hexadecimal
Serial.print(cayenntu);
Serial.println(ntuHex);
cayenneLPPformat = cayenntu + ntuHex ; //Sort the cayenntu and ntuHex values into
the cayenneLPPformat variable. of this condition
Serial.print("cayenneLPPformat = ");
Serial.println(cayenneLPPformat) ;
return cayenneLPPformat; //Returns a value to a void loop.
}

String getSensor3(float ECValue) { //Create a condition of the string variable ECValue.
String ec = "";
String cayenneLPPformat = "";
String cayenec = "0302"; //0302 is the analog input of cayennlpp.
ec = uint16_t(ECValue * 100);
Serial.println(ec);
char ecHex[5];
sprintf(ecHex, "%04lx", ec.toInt()); //Converting decimal to hexadecimal
Serial.print(cayenec);
Serial.println(ecHex);
cayenneLPPformat = cayenec + ecHex ; //Sort the cayenec and ecHex values into the
cayenneLPPformat variable. of this condition
Serial.print("cayenneLPPformat = ");

```

```
Serial.println(cayenneLPPformat) ;  
return cayenneLPPformat; //Returns a value to a void loop.  
}
```

```
String getSensor4(float _lat) {  
String dlat = "";  
String cayenneLPPformat = "";  
Serial.println(_lat);  
String cayenec = "0488";  
dlat = _lat * 10000 ;  
Serial.println(dlat);  
char latHex[5];  
sprintf(latHex, "%06lx", dlat.toInt());  
Serial.print(cayenec);  
Serial.println(latHex);  
cayenneLPPformat = cayenec + latHex ;  
Serial.print("cayenneLPPformat = ");  
Serial.println(cayenneLPPformat) ;  
return cayenneLPPformat;  
}
```

```
String getSensor5(float _lng) {  
String dlng = "";  
String cayenneLPPformat = "";  
Serial.println(_lng);  
dlng = _lng * 10000 ;  
Serial.println(dlng);  
char lngHex[5];  
sprintf(lngHex, "%06lx", dlng.toInt());  
Serial.println(lngHex);  
cayenneLPPformat = lngHex ;  
Serial.print("cayenneLPPformat = ");  
Serial.println(cayenneLPPformat) ;  
return cayenneLPPformat;  
}
```

```
String getSensor6(float DO_value) {  
String DO = "";  
String cayenneLPPformat = "";  
String cayenDO = "0502";  
DO = uint16_t (DO_value / 10) ;  
Serial.println("DO = " + DO);  
char DOHex[5];  
sprintf(DOHex, "%04lx", DO.toInt());  
Serial.print(cayenDO);  
Serial.println(DOHex);  
}
```

```

cayenneLPPformat = cayenDO + DOHex ;
Serial.print("cayenneLPPformat = ");
Serial.println(cayenneLPPformat) ;
return cayenneLPPformat;
}

#include <Wire.h>
#include <TinyGPSPlus.h>
#include <SoftwareSerial.h>
TinyGPSPlus gps;

static const int RXPin = 4, TXPin = 3;
uint32_t i = 0, j = 0;
static const uint32_t GPSBaud = 9600;
SoftwareSerial gps_Serial(RXPin, TXPin);
char buff[128];
String dummy;
String _lat, _lng;
void setup()
{
    Serial.begin(115200);
    gps_Serial.begin(GPSBaud); // Start the software serial port at the GPS's default baud
    Wire.begin();
}
void loop() {

while (gps_Serial.available() > 0)
{
    gps.encode(gps_Serial.read());

    if (gps.location.isUpdated())
    {
        _lat = String(gps.location.lat(),4);
        _lng = String(gps.location.lng(),4);
        // Latitude in degrees (double)
        Serial.print("Latitude= ");
        Serial.print(_lat);
        // Longitude in degrees (double)
        Serial.print(" Longitude= ");
        Serial.println(_lng);

        dummy = String(_lat + "," + _lng + "|");
        dummy.toCharArray(buff, dummy.length());
    }
}
}

```

```
Wire.beginTransmission(6);  
Wire.write(buff);  
Wire.endTransmission();  
  
}  
}  
}
```



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IoT Based Water Quality Monitoring System Using Solar Powered and LoRaWAN

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Abstract—This paper proposed IoT based water quality monitoring system using solar power and LoRaWAN. The objective is to study and develop water quality monitoring systems to make it easier for users or those who want to check water quality to see pH, temperature, turbidity, conductivity, and GPS viewpoint in the Cayenne LPP cloud. The water in front of the department of electronics and telecommunication engineering at the Rajamangala University of Technology Thanyaburi will be decided to be a test field. The various water quality data will be wirelessly transferred to the database on the Cayenne LPP cloud. It's also essential to use the greatest wireless connection method. To transport data in the field, the Low-Power Wide-Area Network and the Long-Range Wide-Area Network will be employed. Moreover, the system can be extended for 36 hours by charging the battery with a solar panel, and the water quality monitoring system error is less than 5%, according to the formula for determining the percentage mistake.

Keywords—Water Quality Monitoring System, LoRaWAN, Solar Powered, Internet of Thing (IoT), Sensor

I. INTRODUCTION

The environment relies on good water quality. Natural habitats, on the other hand, are deteriorating because of human activities. Due to a challenge, maintaining everyone's water supply safe. Reducing pollution and improving wastewater management could be a technique for ensuring the freshwater supply of our ecosystem. Before being discharged into the environment, water normally collects in the reservoir. Fish or other creatures that are sensitive to tainted water are also placed in the reservoir as an additional indicator that the water is being maintained for release back into the ecosystem. Plastic compounds in industrial effluents are difficult to dissolve in water and can be extremely hazardous if it released into the environment without being adequately processed [1].

The Internet of Things (IoT) is a revolutionary new concept that has the potential to improve everything. The IoT is nothing more than a collection of interconnected components. The IoT goal is to enable things to connect with anything and anybody at any time and from any location, via any path, network, or service [2]. Equipment connectivity,

remote monitoring, Bluetooth, Satellite, microcontrollers, and microprocessors are all part of the internet of things. The IoT is a combination of hardware and software technologies for storing, retrieving, and analyzing data, as well as a communications technology that incorporates electronic systems. Using an existing network, lets you control or monitor any object from anywhere on the planet. However, there are several challenges and concerns related to IoT utilization, which have both advantages and disadvantages.

The proposed system makes use of an LPWAN (low-power wide-area network). It's ideal for systems that communicate little amounts of data to other devices. Long distances and years of use on a single battery [3]. LoRa and the LoRaWAN interface make up LPWAN technology. LoRa, a proprietary encoding technique based on the chirp spread spectrum, is the physical component of the technology stack that allows for long-term seamless connectivity (CSS). The medium access control (MAC) protocol is the data connection layer protocol that LoRaWAN specifies [4]. The data connection layer detects physical layer variations and provides a communication protocol for transferring data safely and reliably.

This paper describes the design and implementation of an IoT-based water quality monitoring system that uses a solar-powered and LoRa WAN network to detect pH, temperature, turbidity, conductivity, and GPS position. A solar panel will also be utilized to recharge the battery and investigate the amount of time spent in a cycle period.

II. LORA, LORA WAN COMMUNICATION PROTOCOL, AND SYSTEM ARCHITECTURE

This section covers several LoRa and LoRaWAN properties. Following that, the principles of LoRa and LoRaWAN discussed.

A. LoRa and LoRaWAN Overview

LoRaWAN is a wireless networking standard established by the LoRa Alliance to address several long-range communication issues in IoT deployments [5]. LoRa uses CSS modulation (Chirp Spread Spectrum) to keep the low-power kind of strategy while extending the communication range [5].

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LoRa is a low-power, long-range radiofrequency technology that can be used in many industrial, technical, and medicinal applications. The goal of this design is to extend the battery life of sensor batteries while also lowering the device's cost [6]. SimTech implemented CSS modulation at the LoRa modulation layer. The LoRa Alliance established the LoRa WAN communication protocol specification [7] at the protocol layer.

B. Lora Basic

The frequency range, distribution factor, spectrum, and source code rate of the LoRa radio can be customized [5, 8]. Different energy values and transmitting ranges can be obtained by combining the parameters frequency, encoding rate, going to spread factor, and carrier frequency. These parameters are used to compute the minimum byte rate. The value of the binary digits is described by equation (1).

$$R_{bit} = SF \frac{BW}{2^{SF}} \cdot CR \quad (1)$$

C. Lora Packet Structure

As illustrated in Fig. 1, this frame begins with a preamble, which is essential to ensure that the receiver and transmitter are in sync [9, 10]. Equation (2) can be used to calculate the number of characters $N_{payload}$ used to deliver a payload, as well as a spreading factor and coding rate. The payload code will be used to calculate the time on-air [9].

$$N_{payload} = 8 + \max\left(\text{ceil}\left(\frac{\Theta(PL, SF)}{r(SF)}\right) \frac{1}{CR}, 0\right) \quad (2)$$

Where linear interpolation is the overhead value. $\Theta(PL, SF) = 8 \cdot PL - 4 \cdot SF + 16 + 28 - 2D \cdot H$ the sum of both preamble and payload durations is then used to compute the remaining time on air.

$$T_{packet} = T_{preamble} + T_{payload} \quad (3)$$

The packet, preamble, and payload durations are represented by T_{packet} , $T_{preamble}$, $T_{payload}$, respectively. The duration of the prelude is calculated as follows:

$$T_{preamble} = (8.25 + N_p) \cdot T_{symbol} \quad (4)$$

N_p is the preamble symbol number, and T_{symbol} is the symbol period. It is the amount of time required to send two 2^{SF} chips. Equation (5) is then used to compute the symbol period, keeping in mind that the chip rate equals the bandwidth (BW).

$$T_{symbol} = \frac{2^{SF}}{BW} \quad (5)$$

The equation defines the duration of the payload:

$$T_{payload} = N_{payload} \cdot T_{symbol} \quad (6)$$



Fig. 1. Lora packet structure.

D. LoRaWAN Network Architecture

Construction and design of an efficient and effective LoRaWAN based water quality monitoring system that achieves the objectives as shown in Fig. 2. For the network to function correctly at various phases, it must be precisely

planned. The action plan will be presented in the section after the system design structure and working test technique have been discussed. Go to the Cayenne I.I.P web page for step-by-step access to the pH, temperature, turbidity, conductivity, and location values to be transmitted over the LoRa WAN network. Also, the CAT Starter kit S767S must be coded to connect the pH sensor, temperature sensor, turbidity sensor, conductivity sensor, GPS sensor using C++ language to transmit values over a LoRa WAN network. Especially, the solar panel is applied as a backup power source.

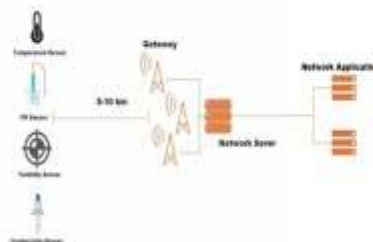


Fig. 2. LoRaWAN network architecture.

III. SYSTEM DESIGN AND IMPLEMENTATION

A. Hardware

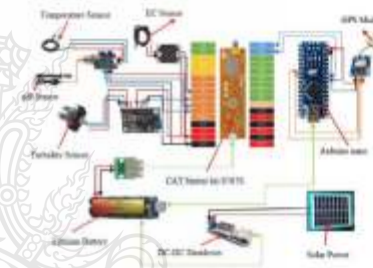


Fig. 3. Structure design.

Turn on the power switch when the solar power is converted to electricity to deliver 5V power to the step-down circuit as shown in Fig. 3. If the power reaches 5V, drop the voltage 5V to the 3.7V battery to the AtsamD21 Cat LoRa WAN and Arduino nano 3.0. A GPS module will send location values to Arduino nano 3.0. and 4 sensors will send the pH, temperature, turbidity, and conductivity values to AtsamD21 Cat LoRa.

In terms of hardware design, the equipment must have a powerful CPU (Central Processing Unit), as well as temperature, turbidity, and maintenance, along with easy connection to other necessary equipment and modification or maintenance, so that it can be maintained and utilized successfully.

On the board CAT Starter kit S767S as shown in Fig. 4, there are turbidity sensors, temperature sensors, pH sensors, GPS module, and Arduino as central processing units. The GPS Module M7 is connected to the Arduino board Nano 3.0, which is connected to the board CAT Starter kit S767S. A dc-dec step-down from the solar panel provides the Lithium voltage to the board CAT Starter kit S767S.

The turbidity sensor is attached to the CAT Starter kit S767S by connecting the Ground (G) pin to the GND pin, the +3V power supply towards the 3V3 pin, and button A (analog pin) to insert A2.



Fig. 4. Details inside the box.

The temperature sensor is connected to the CAT Starter kit S767S board, with the ground pin connected to the GND point and the +3V power pin inserted into the 3V3 pin, as shown in Fig. 4. Pin T2 is inserted into pin A1.

The pH sensor is attached to the CAT Starter kit S767S board, with pin Ground linked to pin GND, power supply pin connected to pin 3V3 and pin P0 connected to the A0 pin.

The electric conductivity (EC) sensor is linked to the CAT Starter kit S767S board, the ground pin is attached to the GND pin, the +5V power supply is connected to the 3V3 pin, and pin A3 (analog pin) is connected to pin A1 (analog pin).

The ground pin of the GPS Module M7 is linked directly to the GND pin on the Arduino Nano 3.0 board, the -5V power supply to the 3V3 pin, and the RX is connected, as seen, TX to D4 and D3 to TX.

The Arduino board Nano 3.0 is closely connected to the CAT Starter kit S767S, and the battery in pin A4 is connected to pin SDA, pin A5 is connected to pin SCL, and the Arduino board 3.0's USB (Universal Serial Bus) is connected to USB in some way, as shown in Fig. 4, with the 3600 mAh battery Vapcell INR18650 Gold Type Lithium Battery.

The Lithium Battery is attached to CAT Starter board, de-de step 5V USB voltmeter module is connected to battery, and polycrystalline silicon solar panel was linked to a two-wire 5 V USB voltmeter module, and power supply through a de-de step down connection. The ground pin is linked to the GND pin, and the 12V power supply pin is connected to the pin.

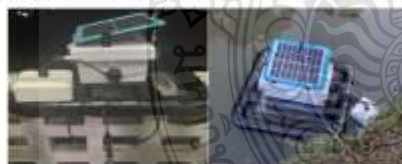


Fig. 5. Details outside the box.

At the Rajamangala University of Technology Thanyaburi, this system was intended to monitor the values of pH, temperature, turbidity, conductivity, and GPS position while using LoRa to broadcast data over a one-kilometer radius. Fig 5 shows a floating buoy with a height of 10.5 inches, a width of 19 inches, and a length of 21 inches, weighing 4.3 kg. PVC pipe is used for the buoyant component, while a polymer with a waterproof rubber coating and heat resistance is used for the equipment storage box. Drill a hole for the watertight connector.

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B. Software program

In the software section, there are programs for writing C++ code, as well as several options within the Cayenne cloud, such as developing the code that will be used in the task. The Arduino IDE is a C++ program with a simple user interface that may be downloaded from the Arduino software. The important code is shown in Fig. 6.

As illustrated in Fig. 6, set the pH variable, declare a pH Vol variable of type float, and use the pH trend equation to create a float type pH value variable. With the library, request a sensor temperature value and declare a temp variable of type float. Also, declare an int type sensorTb variable and a float type ntuTb variable based on the turbidity trend equation. Additionally, set the variable's type to int. To convert from analog to volt, add the rawec value to the equation. Declare the float type ECValueRaw variable from the ec value trend equation. Moreover, the values for the Cayenne LPP brushed sensor are placed in the _payload variable. Set LoRa transmission conditions, then when the conditions are met, display the payload value on the serial monitor. When the criteria are true, the serial monitor will display send payload OK.

```

sensorValue = analogRead(PH);
float pHVol = (float)sensorValue * (3.3 / 1024 / 4);
float pHValue = -0.3204 * pHVol + 21.960;

sensor.requestTemperature();
float Temp = sensor.getTempCByIndex(0);

int sensorTb = analogRead(A2);
float volTb = sensorTb * (3.3 / 1024.0);
float ntuTb = (-0.1707 * volTb) + 3820.4;

float ECValueRaw = analogRead(A3);
float ec = rawec * (3.3 / 1024.0);
float ECValueRaw = (437.24 * ec) - 434.47;
float ECValue = ECValueRaw / 1000;

_payload += d_pH + d_Temp + d_ntu + d_ec + d_M + d_lng + d_MTI; //
if (LoRa.sendPayload(_payload, _payload)) {
  Serial.println(_payload);
  Serial.println("Send Payload OK");
}

```

Fig. 6. Important source code.

C. Real-time water quality monitoring system and test results



Fig. 7. Collected data and processed in real-time from the cloud platform.

Figure 7 illustrates the collected data on the cloud platform in real-time, which includes conductivity, temperature, pH, turbidity, and position values obtained from the four sensors and GPS module.

1) *Electric Conductivity Sensor*: The water transport capacity is determined by the amount of liquid inorganic compounds, which is detected using this method. The conductivity of distilled water is typically between 0.5 and 3 mhos/cm. Conductivity levels between 150 and 500 mhos/cm are beneficial for river fisheries. Some fish species and large crustaceans cannot grow at conductivity values outside of this range. Industrial water has a conductivity of 10,000 mhos/cm, and the results were calculated using a percentage error equation with a standard deviation of less than 2%.

2) *Temperature Sensor*: The Arduino receives analog signal values from the waterproof temperature sensor, making it simple to connect. Temperatures ranging from 0 to 100 degrees Fahrenheit can be detected. Water temperature catalyzes the chemical reaction, lowering the dissolved oxygen level. The water temperature was between 23 and 32 degrees Celsius, and the results were computed using the percentage error equation for a standard deviation of less than 0.5 percent.

3) *pH Sensor*: The Arduino Analog pH Master is a sensor that analyzes the pH value of the water using Arduino's intended Analog signal output, making it simple to use. As stated in table III, the pH was measured between 0 and 14 and the results were calculated using the percentage error calculation for an error percentage of less than 5%.

4) *Turbidity Sensor*: To evaluate the degree of water turbidity, the EC sensor turbidity sensor measures conductivity and light refraction. By adjusting the value of the adjustable resistor, which the values estimated for a percentage error of less than 5% using the percentage error calculation, it operates at 5 volts and provides output analog voltage from 0.4 to 5 volts and digital High/Low.

To calculate percentage of error (%) we use as follows as formular below:

$$\text{Error (\%)} = \frac{\text{Standard Tool} - \text{Measured Value}}{\text{Measured Value}} \times 100 \quad (7)$$

TABLE I. TABLE TESTING PARAMETER OF SENSOR

Testing	Parameters							
	Electric Conductivity		Temperature		pH		Turbidity	
	Standard tool	Measured Value	Standard tool	Measured Value	Standard tool	Measured Value	Standard tool	Measured Value
1	1019.99	1043	29.60	29.70	4.20	3.99	317.00	330.10
2	1019.99	1043	29.60	29.62	4.24	4.12	317.00	330.90
3	1019.99	1042	29.57	29.62	4.21	4.13	317.00	318.00
4	1019.99	1042	29.57	29.65	4.24	4.25	316.00	315.00
5	1019.99	1042	29.57	29.65	4.24	4.30	316.00	315.10
6	1019.99	1040	29.54	29.67	4.25	4.26	316.00	317.00
7	1019.99	1040	29.51	29.68	4.26	4.35	314.00	317.00
8	1019.99	1037	29.57	29.66	4.30	4.31	314.00	319.00
9	1019.99	1037	29.51	29.69	4.30	4.44	313.00	319.00
10	1019.99	1037	29.51	29.60	4.31	4.34	313.00	319.00

5) *GPS Module*: There are at least 24 satellites in this satellite navigation system. The GPS (Global Positioning System) can function in any weather, 24 hours a day, and anywhere in the world. In addition, there are no setup or registration fees. The Ublox Neo-7M GPS Module is designed to receive and track L1/C/A signals transmitted by the GPS at 1575.42 MHz. Also, table II represents the results of the GPS module experiment.

TABLE II. TABLE 5 GPS TESTING

Testing	GPS Module Experimental Results			
	Water quality monitoring system using LoRaWAN		Google Map	
	Latitude	Longitude	Latitude	Longitude
1	14.0376	100.7226	14.037697	100.722612
2	14.0342	100.7260	14.034206	100.726035
3	14.0395	100.7302	14.039535	100.730237

IV. CONCLUSION

This paper presented a study and design IoT based water quality monitoring system that uses solar power and the LoRaWAN network to communicate data to a cloud location and can also display the results of pH, turbidity, temperature, electrical conductivity, and GPS locations while using LoRa to transmit data over a one-kilometer distance. According to the experiment, the system is extended for 36 hours by charging the battery with a solar panel, and the water quality monitoring system error is less than 5%.

There are many more, and if you can put all these theories or knowledge to use in additional research or development, it could be valuable in the future, such as in wastewater treatment systems. Fishponds for diverse households can be used by regulating the aerator to increase the oxygen in the water for aquatic animals. However, additional advances are acceptable for everyone interested in bringing water quality monitoring system via LoRaWAN network to further develop to be more efficient for the ease of remote monitoring via LoRaWAN network. In the future, the proposed system will be completely developed and tested, with the Raspberry Pi serving as the internet of thing LoRaWAN gateway and Arduino based on IoT LoRaWAN sensors.

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