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Constructing an Internet of things wetland monitoring device and a real-time wetland monitoring system

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Abstract. Global climate change and urbanization have various demerits, such as water pollution, flood damage, and deterioration of water circulation. Thus, attention is drawn to Nature-based Solution (NbS) that solve environmental problems in ways that imitate nature. Among the NbS, urban wetlands are facilities that perform functions, such as removing pollutants from a city, improving water circulation, and providing ecological habitats, by strengthening original natural wetland pillars. Frequent monitoring and maintenance are essential for urban wetlands to maintain their performance; therefore, there is a need to apply the Internet of Things (IoT) technology to wetland monitoring. Therefore, in this study, we attempted to develop a real-time wetland monitoring device and interface. Temperature, water temperature, humidity, soil humidity, PM1, PM2.5, and PM10 were measured, and the measurements were taken at 10-minute intervals for three days in both indoor and wetland. Sensors suitable for conditions that needed to be measured and an Arduino MEGA 2560 were connected to enable sensing, and communication modules were connected to transmit data to real-time databases. The transmitted data were displayed on a developed web page. The data measured to verify the monitoring device were compared with data from the Korea meteorological administration and the Korea environment corporation, and the output and upward or downward trend were similar. Moreover, findings from a related patent search indicated that there are a minimal number of instances where information and communication technology (ICT) has been applied in wetland contexts. Hence, it is essential to consider further research, development, and implementation of ICT to address this gap. The results of this study could be the basis for time-series data analysis research using automation, machine learning, or deep learning in urban wetland maintenance.
Keywords: environmental maintenance; internet of things (IoT) technology; nature-based solution (NbS); patent; real-time monitoring; wetland

1. Introduction

The industrial revolution has increased greenhouse gas emissions and changed the global climate. This climate change has caused floods, droughts and desertification, leading to the destruction of ecosystem habitats (Wang and Gu 2021, Salim *et al.* 2019). As the number of urban residents increases, heat island phenomena and air pollution occur, and the impermeable packaging of cities worsens urban water circulation, causing flood damage (Choi *et al.* 2019, Kim *et al.* 2019). Pollutants that worsen the urban water environment, such as organic matter, nutrients, and pathogens, are discharged into the water, causing environmental problems (Maniquiz-Redillas *et al.* 2022, Sungji *et al.* 2020, Kang *et al.* 2011, Kwak and Yun 2020, Jeon *et al.* 2019) Therefore, Nature-based Solution (NbS) is drawing attention as a solution. NbSs are techniques that solve environmental drawbacks in ways that are inspired by nature, and they maintain natural capital and ecosystem services (Liquete *et al.* 2016, Lee *et al.* 2022). NbS methods include urban wetlands, bioretention, and porous pavements. Urban wetlands are artificial wetland facilities located in the city that are designed to solve urbanization limitations by imitating natural wetlands and strengthening their functions (Mitra *et al.* 2006, Mitsch and Gosselink 2007, Choi *et al.* 2019). Urban wetland designs consider the role of filtration, microorganisms, and vegetation in strengthening the physical, chemical, and biological pillars of natural wetlands. In addition to removing pollutants, improving water quality, and storing carbon, urban wetlands also provide ecosystem habitats for cities and serve as public facilities for residents (Kayranli *et al.* 2010, Gorham 1991, Kadlec *et al.* 2000, Holden 2005, Wu *et al.* 2018). To maintain the efficiency of these urban wetlands, frequently checking their conditions and maintaining and operating their components are essential. However, existing wetland monitoring takes too long for humans to participate in all processes from sampling to measurement and acquiring data, as it consumes a lot of manpower.

Therefore, applying the Internet of Things (IoT) technology to urban wetlands to enable rapid monitoring and maintenance is necessary. IoT is a technology that connects various objects using wireless communication, and it is evaluated as an element of the Fourth Industrial Revolution (Diène *et al.* 2020). The IoT consists of sensing, communicating, and interfacing technology. IoT collects information using sensors, establishes communication technologies to exchange information between people and

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objects and between objects and objects, and services it with a user-convenient interface. Currently, IoT is applied in various fields such as logistics and construction, telemedicine, transportation, and agriculture. In the agricultural sector, information is collected from sensors to analyze crop environment, and increase harvest efficiency; in the industrial sector, indoor ozone levels are monitored and notifications are sent in emergencies (Cambra *et al.* 2017, Dudhe *et al.* 2017). In wastewater treatment plants, the application and experimentation of automation technology for the automatic measurement and operation of water quality parameters are being carried out (Kodali *et al.* 2019). Additionally, research is being conducted to measure water quality at specific locations using low-cost sensors (Lakshmikantha *et al.* 2021). gIn addition, new attempts are being made to build big data by collecting data through sensing. Increasing the monitoring efficiency of urban wetland conditions using IoT technology in real-time and automating maintenance are needed. Therefore, in this study, an IoT technology was applied to produce a wetland monitoring device, a website was built to service the acquired data, and the monitoring device was evaluated based on collected data. Furthermore, we reported the use of information and communication technology (ICT) in ongoing developments in this field. Furthermore, we conducted a patent search to investigate the extent to which technological advancements are made in this domain.

2. Materials and methods

2.1 Monitoring device and interface design

The designed monitoring system and interface can be divided into distinct components as illustrated in Fig. 1. These components are a sensing unit that measures the condition of the wetland using selected sensors, a networking unit that converts sensor data into digital signals and transmits them to a web server, and an interface that presents the transmitted information from the web server to the user.

The wetland being monitored encompasses soil, substrate, water, vegetation, and microorganisms that interact synergistically. Vegetation thrives under optimal temperature and humidity, and its growth signifies an enhanced carbon sequestration capacity. In addition, if the soil is maintained with a lot of moisture, gas exchange in the soil layer is hindered, and the soil remains in an anaerobic state, causing plant decay (Laskov *et al.* 2006, Drew 1997, Voesenek *et al.* 2006, Pezeshki and DeLaune 2012). Hence, it is essential to assess factors, such as influent and effluent water and soil moisture, to verify the proper functioning of wetland hydrological processes. To sustain optimal functional conditions and prevent wetland degradation, continuous real-time monitoring is imperative. Furthermore, the monitored outcomes should be communicated in a user-convenient manner, allowing timely user access and intervention. PM(Particulate Matter) concentration and PM removal efficiency are related to the relative humidity and temperature of the wetland. Typically,

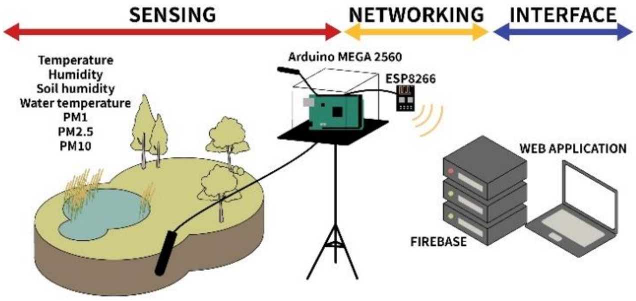


Fig. 1 Structure of real-time wetland monitoring

wetlands increase relative humidity, and high relative humidity is known to be effective in removing PM (Li *et al.* 2019)

The aim of manufacturing a monitoring device in this study is to optimize the performance of artificial wetlands installed in the city and control wetlands. Therefore, selecting sensors to detect factors affecting major elements in wetlands is necessary. To monitor wetland conditions, temperature, humidity, water temperature, soil humidity, and particulate matter (PM_1, $PM_{2.5}$, and PM_{10}) were measured.

2.2 Monitoring region and period

The wetland was constructed within a box with dimensions of 500 × 360 × 360 mm. The soil layer of the wetland comprised gravel, sand, and leaf soil, and six reeds were planted. A continuous inflow of water was provided to the wetland ecosystem throughout the study period. The temperature, humidity, and particulate matter sensors were mounted on the upper part of the wetland, the water temperature sensor was placed in the effluence, and the soil humidity sensor was installed in the soil layer, and it is shown in Fig. 2.

The measurements were taken for approximately three days, from October 28th, 2022 to 23:50 on October 29th, 2022. Indoor measurements were taken until 15:30 on the 28th, after which the observations were shifted outdoors until the conclusion of the study.

2.3 Materials and device development

The most suitable sensors for selected indicators were used for wetland monitoring. Analog data acquired by the sensors were converted into digital data, and a microcontroller capable of connecting many devices was used. The selected materials are shown in Table 1.

Arduino is an open-source electronic platform based on hardware and software. It is suitable for configuring the IoT environment because it has a software programming environment that is inexpensive, enables easy choice implementation and can be equipped with various modules. There are many types of Arduino hardware, and among them, the Arduino Mega2560 board with sufficient input/output pins was selected. ESP 8266 is an inexpensive Wi-Fi microchip with built-in networking software and microcontrollers that can run

Fig. 2 Monitoring region and device

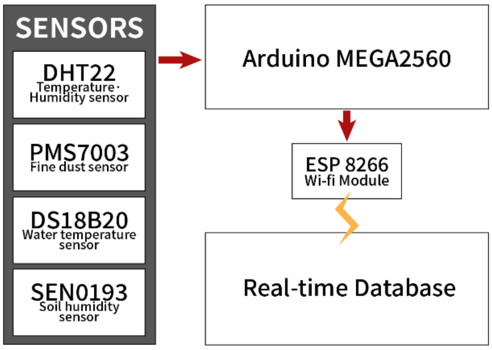


Fig. 3 Block diagram of the IoT (Internet of Things) real-time monitoring devices and web server

Table 1 Description of the materials

Name	Use	Specifications
Arduino MEGA2560		cat.no: XC9203 operating voltage: 5 V digital i/o pins: 54 analog input pins: 16 input voltage (recommended): 7–12 V input voltage (limit): 6–20 V
ESP8266	Wi-Fi module	voltage: 3.3 V size: 25 × 14 × 11 mm pin: RX/GPIO0/GPIO2/VCC/GND/RESET/ENABLE/TX
DHT22	Measuring temperature and humidity	power supply: 3.3–6 V DC temperature operating range: −40 ℃–80 ℃ temperature accuracy: ±0.5 ℃ humidity operating range: 0%–100% humidity accuracy: ±2%
PMS7003	Measuring PM_1, $PM_{2.5}$, and PM_{10}	measurement ranges: 0.3–1.0, 1.0–2.5, 2.5–10 operating voltage: Typ: 5.0 V/Min: 4.5 V/Max: 5.5 V
DS18B20	Measuring water temperature	operating voltage: 3–5.5 V range of measurement: −55 ℃–125 ℃
SEN0193	Measuring soil humidity	operating voltage: 3.3–5.5 VDC output voltage: 0–3.0 VDC range of measurement: 0%–100%

connection applications and provide Wi-Fi connectivity. DHT22 is a sensor that can measure temperature and humidity at the same time. It contains a chip that digitally converts analog signals into digital signals, and it has capacitive humidity sensors and thermistors that measure humidity and temperature, respectively. PMS7003 is a fine dust sensor that can measure PM_1, $PM_{2.5}$, and PM_{10} simultaneously using the laser measurement method. It contains an air circulation fan, so it can continuously circulate the air to be measured; it is also equipped with a module that converts analog data into digital data. DS18B20 is a waterproof contact-type temperature-measuring sensor probe that can continuously measure the temperature of the water it is immersed in. SEN0193 is a corrosion-resistant sensor that adopts the principle of capacitive sensing to measure moisture in the soil, and it can be used for a while. The device was attached to a tripod with adjustable height and installed in a perforated acrylic box to protect it from other failure risks, including rain. The materials are connected to form the monitoring device as shown in Fig. 3 The sensor transmits the sensed results to Arduino MEGA 2560. This result is transmitted to the real-time database of the Firebase via network communication using ESP8266.

For the device to work, uploading the code to Arduino MEGA 2560 and ESP8266 after programming is necessary. The code was written using C++, compiled using Arduino IDE, and uploaded (Srivastava *et al.* 2018). Arduino MEGA 2560 uploaded a code that collects sensed data and transmits it to ESP8266, and ESP8266 uploaded a code that transmits it over the network to be stored as a JSON object in the Firebase real-time database. JSON (JavaScript Object Notation) is a lightweight data format used for storing and exchanging data, making it highly effective for data exchange in web applications. Web pages are built using hypertext markup language and cascading style sheets to check the transmitted data, and dynamic elements are added with JavaScript to update and display the latest data in real-time.

2.4 Research on patents for applying ICT to wetlands

Monitoring of wetlands consumes a significant amount of time and human resources. As mentioned earlier, in other fields, monitoring integrated with ICT technology is actively utilized, but wetlands have not seen such extensive adoption of ICT technologies. Therefore, to assess the extent of attempts to apply ICT technologies to wetlands, we conducted a patent search related to wetlands.

To investigate trends in wetland-related technologies and identify instances of ICT integration in wetland gathered from Korea intellectual property rights information service (KIPRIS) from January 2011 to August 2023. The keywords utilized for the search were “wetland” and “ICT.” To ascertain the annual distribution of patent applications, corresponding year-specific data was also collected. Additionally, to discern patent application inclinations, relevant international patent classification (IPC) codes were amassed. This method has been utilized in both Korean patent searches and international patent searches.

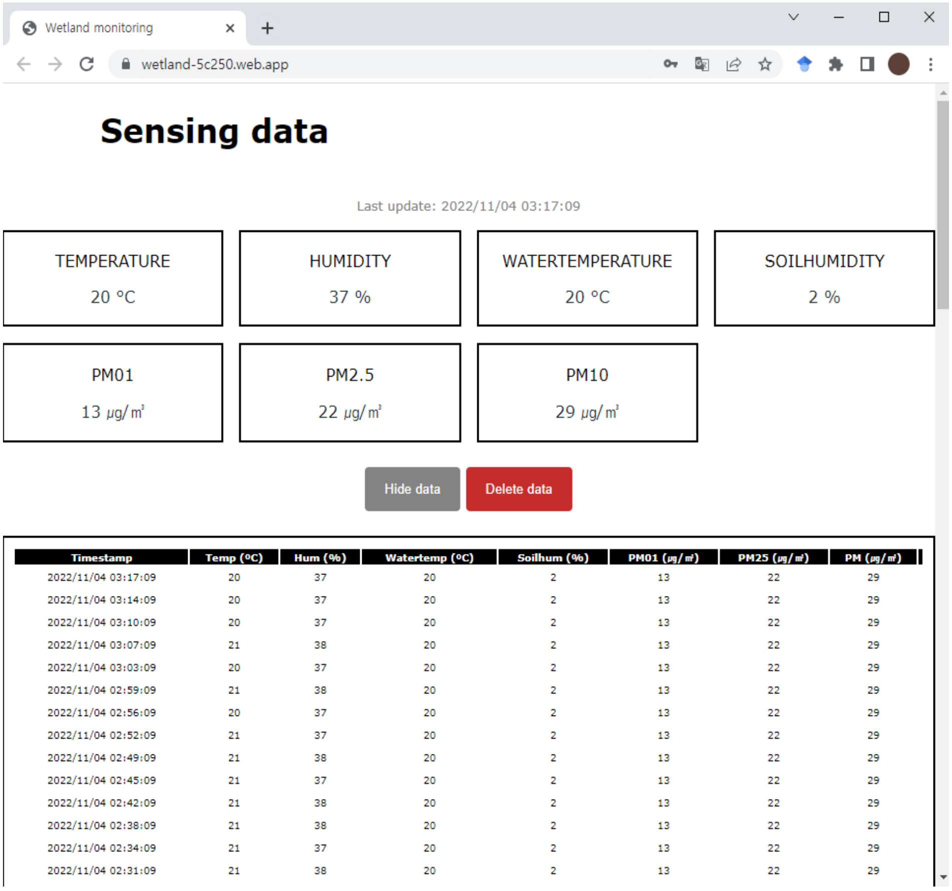


Fig. 4 Created web page interface for desktop and mobile

3. Results and discussion

3.1 Produced wetland monitoring devices and web pages

The produced device designed was installed at the monitoring site. Fig. 4 presents a web page where the data acquired through the monitoring device are displayed. The web page supports both desktop and mobile formats, enabling access to the latest results from anywhere.

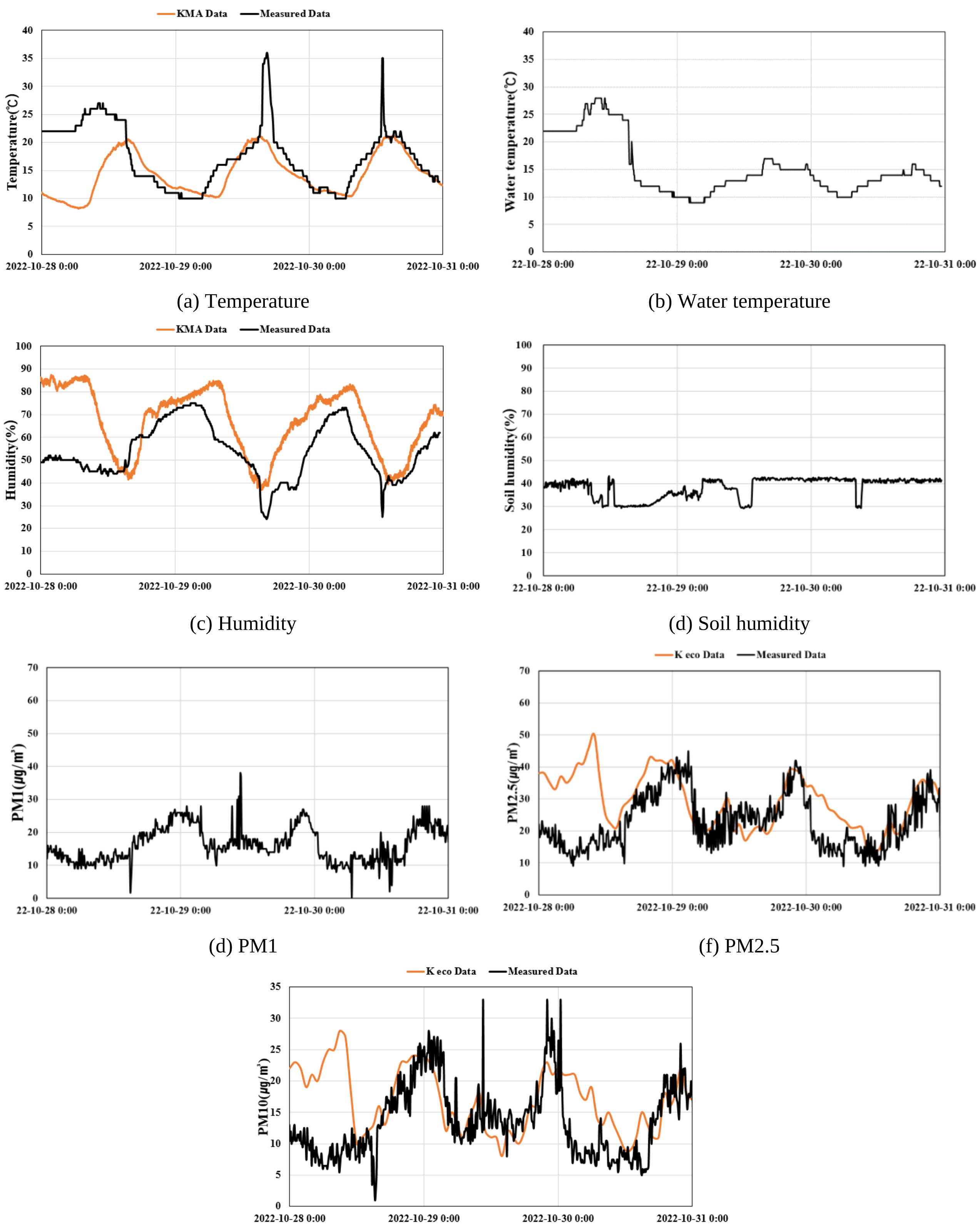
3.2 Comparing the measured data

Each indicator, including temperature, humidity, water temperature, soil humidity, PM1, PM2.5, and PM10, was measured using sensors attached to the device. Fig. 5 shows the graphical form of the data for each indicator collected over 3 days without any missing value.

During the indoor measurement period, the indoor temperature was higher than the outdoor temperature, resulting in higher values compared with the data from the Korea meteorological administration (KMA). Similar patterns were observed during the outdoor measurement period. Although the values for the water temperature measured indoors were high, they exhibited a smaller but comparable fluctuation pattern compared with values from outdoor measurements. The values for humidity also showed a similar pattern to temperature values. Regarding both temperature and humidity, a spike in temperature occurred around 16:20 on the 29th, accompanied by a decrease in humidity. A similar phenomenon occurred around 13:00 on the 30th that is attributed to the temperature and humidity sensor being affected by direct exposure to sunlight. Immediate measures were taken, and the temperature and humidity data returned to a normal state at a faster rate than they did on the 29th.

Soil humidity, due to the deep placement of the sensor within the wetland and continuous water inflow, exhibited consistent values over the 3 days. The fine particulate matter indicators, PM1, PM2.5, and PM10 demonstrated similar upward and downward trends. Comparing the PM2.5 and PM10 measured data with data from the Korea environment corporation (KECO), during the indoor measurement period, PM2.5 values were lower than the values from KECO data, but the values were similar for the outdoor measurement period.

When comparing data from KMA and KECO, specifically for temperature, humidity, PM2.5, and PM10, similar trends and fluctuation patterns were observed, although they were not perfectly aligned. This discrepancy is attributed to regional differences between the KMA and KECO measurement locations. The distance from the wetland monitoring device to the nearest KMA measurement point is 12.1 km, and to the nearest KECO measurement point is 1.4 km. The existence of such regional disparities makes it challenging for both sets of data to align perfectly.



(a) Temperature (b) Water temperature

(c) Humidity (d) Soil humidity

(d) PM1 (f) PM2.5

(g) PM10

Fig. 5 Measured data for selected indicators

3.3 Analysis of patents for applying ICT to wetlands

We studied patents in South Korea and abroad. The graph in Fig. 6 summarizes the number of patent applicaions filed in South Korea from January 2011 to August 2023. Fig. 7 provides the top 10 IPC codes for the investigated patents. Table 2 presents a summary of the content of the top 10 IPC codes from Fig. 7. For domestic patents, there is

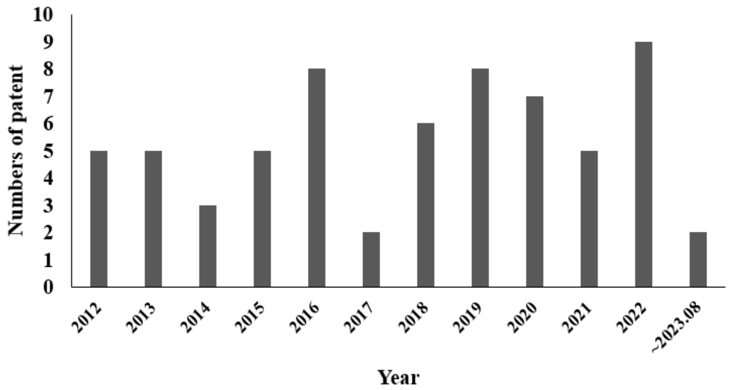


Fig. 6 Number of domestic Korean patent applications per annum

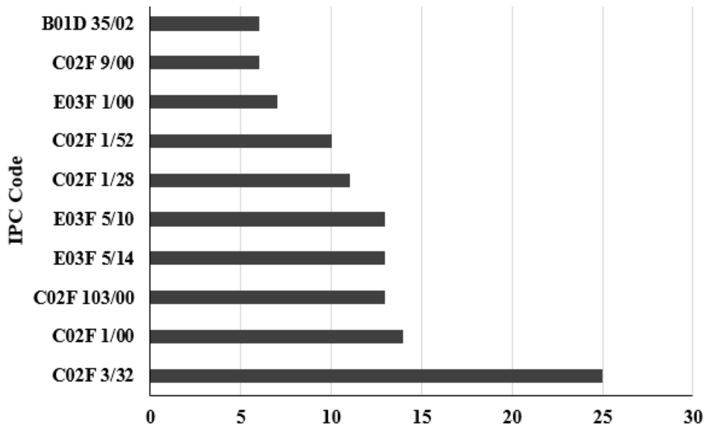


Fig. 7 IPC codes and their occurrences in domestic patent applications in Korea.

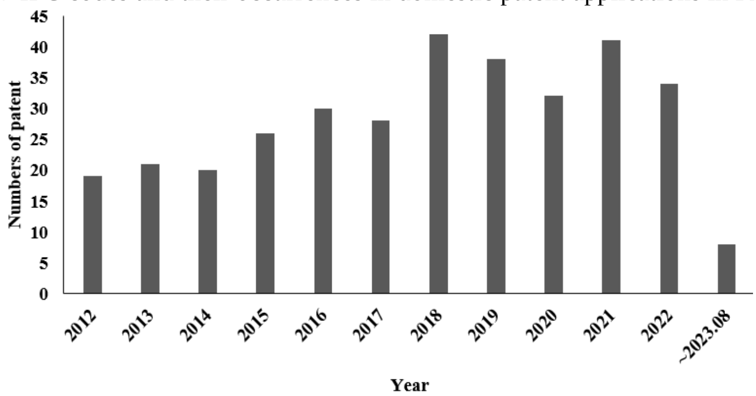


Fig. 8 Number of international patent applications per annum

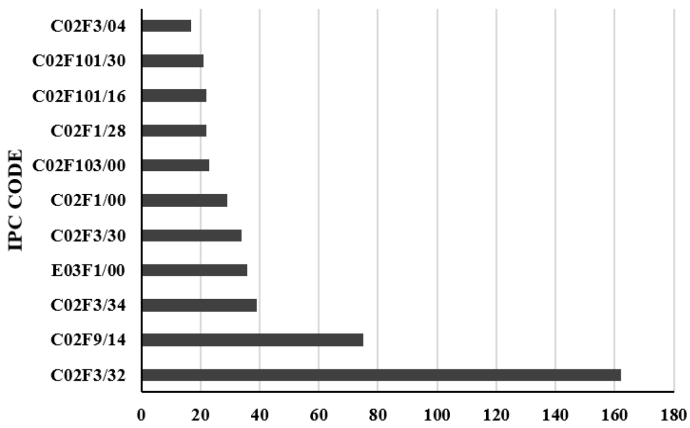


Fig. 9 International patent classification codes and their occurrences in international patent applications

Table 2 Interpretation of used IPC codes in Korean domestic patents

IPC Code	Numbers	Content
C02F 3/32	25	Characterized by the animals or plants used, e.g. algae
C02F 1/00	14	Treatment of water, waste water, or sewage (C02F3/00 ~ C02F9/00 take precedence)
C02F 103/00	13	Nature of the water, waste water, sewage or sludge to be treated
E03F 5/14	13	Devices for separating liquid or solid substances from sewage, e.g. sand or sludge traps, rakes or grates(for use in sewage purification plants or in sewage purification plants or sewer systems B01D, C02F)
E03F 5/10	13	Collecting tanks; Equalising tanks for regulating the run-off; andLaying-up basins
C02F 1/28	11	By sorption (using ion-exchange C02F1/42; sorbent compositions B01J)
C02F 1/52	10	By flocculation or precipitation of suspended impurities
E03F 1/00	7	Methods, systems, or installations for draining-off sewage or stormwater
C02F 9/00	6	Multistage treatment of water, wastewater, or sewage
B01D 35/02	6	Rigidly mounted in or on tanks or reservoirs(B01D 35/04 takes precedence)

Table 3 Interpretation of used international IPC codes

IPC Code	Numbers	Content
C02F3/32	162	Characterized by animals or plants used, e.g. algae
C02F9/14	75	At least one step being a biological treatment
C02F3/34	39	Characterized by the microorganisms used [3,2006.01]
E03F1/00	36	Methods, systems, or installations for draining-off sewage or stormwater
C02F3/30	34	Aerobic and anaerobic processes
C02F1/00	29	Treatment of water, waste water, or sewage(C02F 3/00 ~ C02F 9/00 take precedence)
C02F103/00	23	Nature of water, wastewater, sewage or sludge to be treated
C02F1/28	22	y sorption (using ion-exchange C02F1/42; sorbent compositions B01J)
C02F101/16	22	Nitrogen compounds, e.g. ammonia
C02F101/30	21	Organic compounds

a slight upward trend in the number of applications over time. The most frequent IPC code in South Korean domestic patents is C02F 3/32, characterized by animal or plant use, with 25 contexts, a comprehensive search of patented technological innovations was conducted. This encompassed exploring both domestic patent applications within South Korea and international patents. The search was executed and data was cases. The second and third rankings are C02F 1/00, related to water treatment, waste water, or sewage, with 14 cases, and C02F 103/00, related to the nature of the treated water, waste water, sewage, or sludge, with 13 cases, respectively. IPC codes related to ICT management or control did not appear in the top 10, but G06Q 50/10, representing content provision, management, editing, monitoring, and control services via communication networks, was 13th with four cases.

The graph in Fig. 8 summarizes the number of patent applications filed overseas, searchable on KIPRIS, from January 2011 to August 2023. Fig. 9 provides the top 10 IPC codes based on the investigated overseas patents. Table 3 presents a summary of the content of the top 10 IPC codes from Fig. 9. For overseas patents, there is an upward trend in applications related to wetland-related technologies over time. The most frequent code is C02F 3/32, which is the same as the top code for domestic patents, with 162 cases. The second and third most frequent codes are C02F 9/14 and C02F 3/34, characterized by at least one biological treatment step and having specific microorganism characteristics, respectively. No IPC codes related to ICT and management or control were found in the top 10.

It appears that the development of management/control techniques for applying ICT to wetlands is relatively limited compared to developing wetland technology itself.

4. Conclusions

In this study, a wetland monitoring device was developed, and an interface was implemented to display real-time monitoring results.

• The wetland monitoring device was constructed by attaching temperature, humidity, water temperature, soil moisture, and fine dust sensors to an Arduino MEGA 2560, and a web page was created to display the transmitted data through a communication module.

• Using the developed monitoring system, measurements were taken without any missing data for three days. The results were compared with data from KMA and KECO, confirming similar upward and downward trends. The discrepancies were attributed to inexpensive sensors limiting the device and environmental differences from agency measurement points.

• The patent investigation revealed an upward trend in both domestic and foreign patent applications in Korea. The analysis of IPC codes indicated that the development of management/control techniques for applying ICT to wetlands is relatively limited.

• Given the utility of the research results and the current underdeveloped status of the technology, it is evident that the application of ICT to develop management and control techniques for wetland monitoring is a necessity. This study can serve as a foundation for automated wetland maintenance, time-series data analysis using machine learning or deep learning, and related research.

Acknowledgments

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