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Short Paper

The Use of Microcontrollers in Air Quality Monitoring: A Systematic Literature Review

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Abstract

Purpose – this paper aimed at identifying the low-cost technologies using microcontrollers like Arduino and Raspberry Pi used in air quality monitoring in the Philippines for 2023.

Method – This paper utilized a systematic literature review that employed strategies in selecting, analyzing, evaluating, and summarizing papers from a database of documents. Similarly, inclusion/exclusion criteria were set.

Results – Using the web address of Google Scholar which is scholar.google.com, a search result for the keywords "microcontrollers arduino raspberry pi air quality monitoring Philippines" returned 109 results.

Conclusion – Air quality monitoring can be done using a low-cost microcontroller like Arduino or Raspberry Pi. An effective solution for pollution monitoring using a wireless sensor network to provide real time pollution data.

Recommendations – To encourage developers to develop an air quality monitoring system using Arduino or Raspberry Pi microcontrollers with integrated sensors.

Research Implications – This research seeks to identify the current air quality monitoring systems for 2023 using Arduino or Raspberry Pi microcontrollers.

Practical Implications – This research proves that technology offers cheaper alternatives in the development of air quality monitoring systems.

Social Implications – This research shows opportunities for students to use technology.

Keywords – Microcontroller, IoT, Arduino, Raspberry Pi, Air Pollutants

INTRODUCTION

Air is cardinal for us as humans. It is what we breathe. It is composed of several gasses and particles in the atmosphere like nitrogen, oxygen, argon, carbon dioxide, water vapor, and other gasses. Air, considered important for our existence on Earth, has issues primarily with its quality. Air quality is one of the key measures to be closely observed in real-time in today's urban environments because it has an impact on human health, safety and comfort. Particulate matter with 2.5 micrometers can be measured by some gas sensors. A sensor was integrated into microcontroller computer to measure dust and particle matters (Idrees et al, 2018).

Air pollution is the state when there is an alteration in atmospheric air parameters which is detrimental to living things. Vehicle emissions, industrial emissions, deforestation, and the likes are one of the causes of air pollution. Exposure to these emissions which contain mercury, particulate matter, lead, and other harmful gasses can debilitate human health. According to the study of Kampa and Castanas (2008), there are plethora of ways wherein air pollutants can cause harm to human beings. Emission from vehicles affects the atmospheric composition of the air. Air pollution has both acute and chronic effects on human health which affects several different systems and organs in our body. It can range from minor upper respiratory irritation to chronic respiratory conditions such as heart disease, lung cancer, bronchitis. It can also aggravate pre-existing heart and lung disease, or asthmatic attacks. Air pollutants like carbon monoxide, sulfur dioxide, nitrogen oxides, volatile organic compounds, and the like can cause acute and chronic diseases to human beings. Examples are respiratory diseases, heart diseases, lung diseases, and many more. These contribute to high human mortality rate. In the study of Fenger (1999), he stated that air pollutants can be divided into two groups namely: the traditional major air pollutants comprising of sulfur dioxide, nitrogen dioxide, carbon monoxide, particles, lead and the hazardous air pollutants comprising of chemical, physical and biological agents of different types.

The advent of technology in environmental monitoring has considerably utilized the use of computers in gathering parameters especially in the air since air pollution is still a crucial concern. Monitoring air quality has evolved from manual parameter readings to the use of sensors that transmit data in a computer. According to Marinov et al. (2016), the use of multi-parameter air quality monitoring systems makes it possible to do a detailed level analysis of major pollutants and their sources. These monitoring systems are cardinal components for monitoring air quality and for controlling the main pollutant concentrations in urban area. Low-cost sensors can be easily integrated into microcontrollers such as Arduino and Raspberry PI. It is expected to reduce costs associated with operations and logistics of these technologies (de Camargo et al., 2023). Having cheaper technologies would present opportunities in ensuring air quality monitoring can be done with ease. In addition, this paper aimed at identifying the low-cost existing technologies using microcontroller used in air quality monitoring in the Philippines for 2023.

LITERATURE REVIEW

Microcontrollers

Microcontroller is a low-cost compact computer that has the ability to do specific instructions. It is composed of a processor, a memory, and input/output peripherals. Microcontrollers are typically found in robots, vehicles, home appliances, mobile phones, and many more. Microcontrollers can be classified in terms of number of bits, memory devices, memory architecture, and instruction set. There are tons of microcontrollers to use especially in monitoring the air quality. An example of a microcontroller is shown on figure 1. It is called the Raspberry Pi. Other microcontrollers are PIC, Arduino, and many more. Android mobile applications can also be integrated to microcontrollers (Sabado, 2024).

Air pollution is a crucial concern especially for the living. These pollutants are detrimental to human health. Monitoring air pollution can be done easily with microcontrollers.

According to Moyes (2024), the top three popular microcontrollers are Arduino, Raspberry Pi, and Espressif Systems (ESP32).

Internet of Things

According to Wu et al. (2020), Internet of Things or commonly known as IoT refers to a network of low-cost electronic devices that can communicate and share data. This can be done by connecting small computers or microcontrollers to the internet to enable them to collect and exchange data without requiring human intervention. IoT systems normally consist of sensors that monitor parameters like air pollutants.

The introduction of the Internet of Things makes data gathering simple through the use of computers and the internet. Microcontrollers like Arduino and Raspberry Pi can be integrated along with gas sensors to monitor the air quality parameters. Through the wireless sensor network, transmitting and receiving of data can be done in a simple click.

Arduino

Arduino is an open-source computer hardware and software company which started as Arduino Project in Italy. According to Saikumar et al. (2017), Arduino is a popular microcontroller module which is connected to a computer via serial communication. It has fourteen numerical input/output pins, six analog inputs, a 16-megacycle quartz oscillator, a USB affiliation, an influence jack, associate ICSP pass, and a retune switch. It contains everything required to support the microcontroller.

Figure 1. Arduino Uno R3 Microcontroller

The figure 1 shows the microcontroller called Arduino. Microcontrollers can be used in monitoring air quality with the help of the sensors connected to it.

Arduino in Air Quality Monitoring

Arduino microcontrollers have several variants depending on certain factors. In the study of Manna et al. (2014), an Arduino microcontroller board based on the ATmega328 was used to integrate carbon monoxide and sulfur dioxide sensor modules. It can transmit data to a server via internet connection as well. In a similar study of Abraham and Li (2014), an Atmega328 was used in an Arduino Uno board which is connected to a carbon dioxide sensor, volatile organic compounds sensor, and carbon monoxide sensor.

Installing an Arduino on an unmanned aerial vehicle (UAV) is on a different level. Monitoring air quality using small sensors onboard with an unmanned aerial vehicle is very complicated. A system developed and evaluated in consisting of a UAV, an Arduino MEGA 2560 microcontroller and integrated with four gas sensors for carbon monoxide, carbon dioxide, nitrogen oxide, and nitrogen dioxide were used in measuring air pollution

The UAV will have an RC receiver and the ground station where the computer is located will have the RC transmitter (Villa et al., 2016).

A low-cost RFID based application can be designed using 8-bit Atmel AVR microcontrollers or 32-bit Atmel ARM processors. A vehicle unit consisting of a carbon dioxide sensor and RFID transmits values to a remote computer via GSM modem (Rajalakshmi et al., 2015). Arduino Uno R3 microcontroller is shown in the next figure. It is the most flexible hardware platform used based on ATmega328P which can be programmed according to the function where it is to be used. It can be integrated with the MQ135 Gas Sensor and it can measure carbon dioxide, sulfur dioxide, nitrogen dioxide, and liquefied petroleum gas. According to Arduino Online Store, Arduino Uno is considered as the most used and most documented board of the whole Arduino family. Uno which comes from an Italian word which means one (Pal et al., 2015).

Moreover, Arduino can be used in air pollution monitoring. Integrated with gas sensors, it is low cost and can collect concentrations of nitrogen dioxide, carbon dioxide, and carbon monoxide. This microcontroller was integrated with gas sensors and installed in a windowsill about 4m from the ground. The data gathered is forwarded to a server that collects data. It is called AirQino (Zaldei et al., 2015). Another air pollution monitoring study using Arduino was done at King Faisai University. In here, an MQ2 gas sensor was integrated in Arduino and it collects carbon monoxide and liquid petroleum gas (Al-Haija et al., 2013). MQ135 is another sensor that can also be integrated on Arduino Uno R3 for it can sense ammonia, nitrogen oxides, carbon dioxide, and some other gasses (Nirosha et al., 2017).

Similarly, a sensor array could be connected to an air monitoring system that would monitor air pollution in real time and predict the measurements in the next given time interval. The data would be sent to the network via WiFi connectivity. The system consisted of Arduino UNO, a ESP8266 WiFi module, and MQ2 gas sensor for the initial stage development (Elvitigala & Sudantha, 2017). Another study using Arduino UNO board with Wi-Fi module is used as an embedded device for sensing and storing the data in the cloud. Sensors are connected to Arduino UNO boards for monitoring and corresponding sensor reading will be sent via Wi-Fi connection (Joshi, 2017).

Raspberry Pi

Raspberry Pi is also a common microcontroller. This device is technically a portable computer and uses the Linux operating system. Figure 2 shows the microcontroller called Raspberry Pi. Presently, the Internet of things (IOT) is a buzzword. Almost anything can be controlled using microcontrollers and interconnecting different electronic devices through a variety of technologies can be made possible.

Figure 2. Raspberry Pi Microcontroller

Raspberry Pi in Monitoring Air Quality

An effective solution for pollution monitoring using a wireless sensor network to provide real time pollution data. Server for storing the pollution level is called Pollution Server (Sirsikar and Karemore, 2015). There is a study using the Internet of Things to gather air parameters. For air pollution, nitrogen dioxide and carbon monoxide will be measured by the following sensors namely: MICS-5525 and MICS-2710 (Saha et al., 2017). There are several uses of Raspberry Pi especially in terms of Air Quality Monitoring. For example, a plug and play, easy to use type of electronic shield called GrovePi+ is integrated with Raspberry Pi. The GrovePi+ hardware shield communicates using the i2c interface. The grovepi+ sensors can collect carbon monoxide, carbon dioxide, ammonia, and nitrogen oxides. These data can be transmitted to a server (Balasubramaniyan and Manivannan, 2016). Apart from monitoring air parameters like carbon monoxide, Raspberry Pi can also be integrated with other sensors like temperature, humidity, and pressure. It can be connected wirelessly via Wifi or via cable using ethernet port (Shete and Agrawal, 2016).

A similar prototype was done using a Raspberry Pi based system associated with carbon monoxide sensor and carbon dioxide sensor with the inclusions of temperature, humidity sensor, and dust sensors (Acharyya et al., 2017). Another IOT related system is the use of Raspberry Pi integrated with DHT22 which measures Humidity & Temperature, a MICS-2710 which is a nitrogen dioxide sensor, and MICS-5525 which is a carbon monoxide sensor. The system has been tested to detect pollutant gasses, temperature, and humidity (Alkandari and Moein, 2018). Similar IOT based system is using Raspberry Pi with gas sensors namely: MQ-6, MQ-7, and MQ135. These gas sensors collect carbon monoxide, liquefied petroleum gas, methane, and butane data (Kavitha et al., 2018).

Another use for Raspberry Pi is the implementation with sensors for light, carbon dioxide, formaldehyde, and temperature. The idea is to transmit collected parameters via a GSM cellular network to the internet and from there it can be accessed using cellular phones and computers (Tapashetti et al., 2019). Indeed, IOT plays a vital role in our society. The Internet of Things is converging with cloud computing and offers a novel technique for better management of data coming from different sensors. Data collected will be uploaded to a cloud server transmitted by low power and low-cost ARM based Raspberry Pi. This Raspberry Pi monitoring system measures various parameters like PM 2.5, carbon monoxide, carbon dioxide, temperature, humidity and air pressure (Kumar and Jasuja, 2017).

Air quality monitoring can also be done in university classrooms. The system collects online data from carbon dioxide sensors that are installed in classrooms along with Raspberry PI. It transmits information over the web interface. Air quality parameters such as carbon dioxide concentration, temperature, and humidity are gathered from different classrooms simultaneously (Balta et al, 2017). Similarly, using the Raspberry Pi platform, an alarm is triggered to indicate high concentrations of emissions. This will serve as a warning to the authorities about the air pollution rate. Air pollution parameters are taken from the low-cost gas sensors. The parameters include: concentrations of smoke, carbon monoxide and nitrogen dioxide, temperature, and humidity (Sivasankari, 2017). The quality of air has been affected by various factors like industrial emission, vehicular transmission etc. The evolution of various technologies like Raspberry Pi has made it easier to deploy sensors and to detect the quality of air in real time. Another prototype using Raspberry Pi is its integration with MQ2, MQ7, and MQ135 sensors. Along with a DHT sensor to gauge temperature. This can measure carbon monoxide, carbon dioxide, methane, and temperature (Kirthima & Raghunath, 2017).

Air Pollutants

Air Pollutants can be found anywhere. According to Luke Curtis et at (2006), several studies have linked air pollutants to several types of health problems including the respiratory, cardiovascular, immunological, hematological, neurological and reproductive/ developmental systems.

Here are the common Air Pollutants:

- Carbon Monoxide
- Carbon Dioxide
- Nitrogen Dioxide
- Particulate Matter (PM10 and PM2.5)
- Sulfur Dioxide
- Lead
- Ozone

Carbon Monoxide mostly comes from vehicle emissions. Exposure to this makes a person dizzy and can experience headaches. High exposure could be fatal.

Carbon Dioxide, as we all know, is the air we breathe out. Breathing difficulty happens when there's a high amount of carbon dioxide.

Nitrogen Dioxide also comes from vehicle emissions and plant emissions. Exposure to this can lead to respiratory problems.

Particulate matter can come from road dust, etc. It can also lead to respiratory problems like asthma.

Sulfur Dioxide usually comes from power plants. It can irritate respiratory systems and affects the throat.

Lead comes from cars and power plants. Exposure to this can lead to kidney and IQ problems.

Ozone comes from burning gas, coals, and other fossil fuels. It can lead to respiratory problems and can also affect plants.

The above-mentioned air pollutants can be measured by sensors. Sensors can be integrated to a microcontroller to retrieve data. Usually, gathered data can be transmitted to a server wirelessly via Wifi module and Bluetooth module.

METHODOLOGY

A systematic literature review is a study method that employs strategies in selecting, analyzing, evaluating, and summarizing papers from a database of documents on the topic to obtain a consistent investigation and even provide directions for future research. Similarly, it is the process of defining inclusion/exclusion criteria, screening titles/abstracts, and thoroughly reading selected works to provide a comprehensive overview of the current state of knowledge on a particular subject. (Peixe et al., 2024).

Systematic Literature Review Process

Google Scholar was used to search for literatures. Google Scholar is an academic search engine of Google. According to Jacsó (2005), Google Scholar is a search engine launched in November 2004. It is designed to help users find scholarly articles, theses, books, conference papers, and court opinions. Through Google Scholar, the users can access academic resources for free.

The literatures reviewed in this paper were composed of microcontrollers like the Arduino and the Raspberry Pi used in air quality monitoring in the Philippines. The author used specific keywords in this paper review.

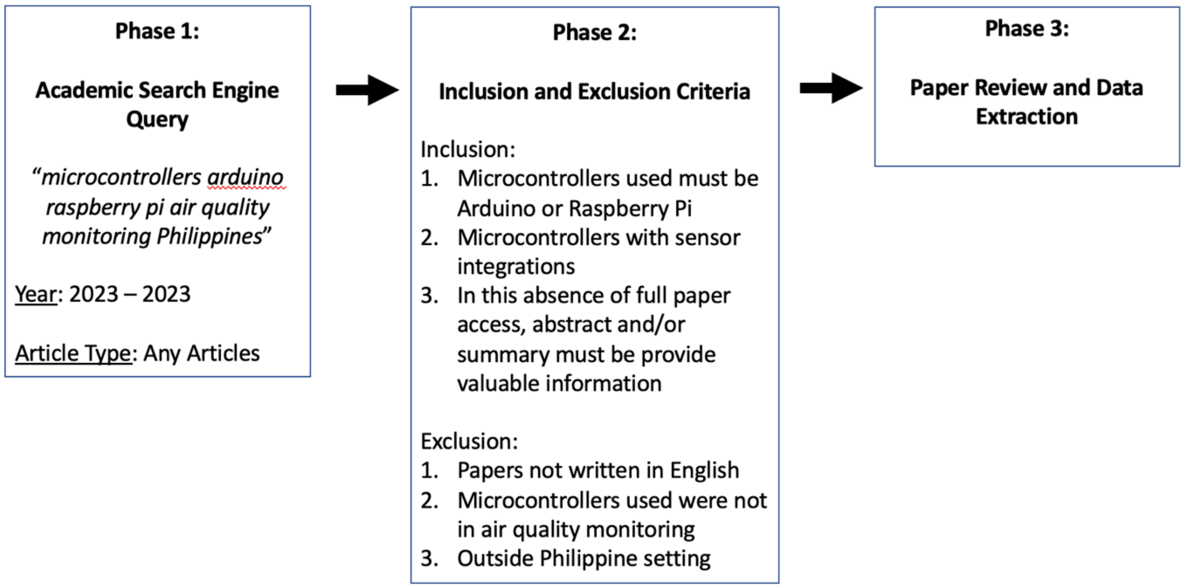

Figure 3. Systematic Literature Review Process

Figure 3 shows the systematic review process in this paper. Phase 1 indicated that specific keywords were used, together with the filters for article year and type. Phase 2 shows the inclusion and exclusion criteria in order to properly filter the results of the academic search engine, Google Scholar. Phase 3 is the paper review and data extraction

The author decided to include papers published from the year 2023 only. Papers published from 2022 and earlier and from 2024 are not considered. The paper needs to be of a developmental type using microcontrollers with sensor integrations. The prototype must be focused on measuring the air pollutants.

RESULTS

Using the web address of Google Scholar which is scholar.google.com, a search result for the keywords "microcontrollers arduino raspberry pi air quality monitoring Philippines" returned 109 results.

Table 1. Summary of Search Results

	With Full Paper Access	With Abstract/ Summary	English Paper	Philippine settings	Arduino or Raspberry Pi Microcontrollers	For Air Quality Monitoring
Yes	23	109	109	33	96	9
No	86	0	0	76	13	100
TOTAL	109	109	109	109	109	109

Table 1 shows the summary of the search results in Google Scholar. The With Full Paper Access column means that the full paper is available in google scholar. The With Abstract / Summary column means that the abstract or summary is available. The English Paper column means that the paper is written in English. The Philippine settings column means that the air quality monitoring technology was used in the Philippines. The With Arduino or Raspberry Pi Microcontrollers column means that the paper discussed the Arduino or Raspberry Pi microcontrollers in its contents. The Air Quality Monitoring column means that the technology was used for air monitoring.

DISCUSSION

Academic Search Engine Results

It is crucial to use valid keywords in the academic search engine like Google Scholar in order to get the reliable results. The author observed that the use of too many keywords returned few results and few keywords returned several results.

Out of the 109 papers reviewed, only 23 had the full access and 86 had no full access as shown in Table 1. Similarly, the 109 papers have abstracts or summaries and were are written in English. The 33 papers were based in the Philippine settings and 76 papers were not based in the Philippines. The 96 papers indicated that it used an Arduino or Raspberry Pi microcontroller and 13 used different type of microcontrollers. Lastly, out of the 109 papers, only 9 papers were used microcontrollers in air quality monitoring.

It is also worth to note that not all search results are valid that is why it is important to scrutinize each result to validate the data. One of the search results was a paper published in 2017 and not in 2023.

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria in this study are as follows: (1) The microcontrollers must be an Arduino or Raspberry Pi only; (2) The microcontrollers must have sensor integrations to be used in air quality monitoring; (3) In case that the full paper is not available, the abstract and/or summary must valuable information; (4) The papers must be written using the English language; and (5) The settings must be in the Philippines.

Out of the 109 searched results using the google Scholar search engine, no paper passed the inclusion and exclusion criteria. These papers were published in the year 2023. The research paper with the title: Low-Cost Air Quality Monitoring System for the Local Government Units of the Province of Rizal came close but the microcontroller used was ESP32. ESP32 is a different type microcontroller. Additionally, the research paper with the title: A Smart-home Electronic-Nose for Detecting Hazardous Gases and Development of a Platform for Monitoring the Levels of Dispersed Oxygen in River Components of a Water Supply Micro Basin Using Programmable Microcontrollers papers were based not in the Philippines.

Air Quality Monitoring System

Most microcontrollers with integrated sensors can measure carbon monoxide, carbon dioxide, nitrogen dioxide, nitrogen monoxide, sulfur dioxide, liquid petroleum gas, particulate matter, ammonia, volatile organic compounds, methane, formaldehyde, and butane.

The 109 search results did not meet the inclusion and exclusion criteria set in this study. The searched results indicates that there's no Arduino or Raspberry Pi microcontroller was developed for the year 2023 used in air quality monitoring.

CONCLUSIONS AND RECOMMENDATIONS

Air quality monitoring can be done using a low-cost microcontroller like Arduino or Raspberry Pi. An effective solution for pollution monitoring using a wireless sensor network to provide real time pollution data.

The use of Systematic Literature Review is ideal in selecting, analyzing, evaluating, and summarizing papers from a database of documents. The meticulous method is time-consuming. It is therefore recommended to use available software or online tools that can make the process of systematic literature review efficient. Consider adjusting the inclusion and exclusion criteria. Try academic databases too.

Developers can explore in developing air quality monitoring system using the abovementioned microcontrollers.

IMPLICATIONS

The absence of air quality monitoring system using Arduino or Raspberry Pi microcontrollers in Google Scholar could imply that other microcontrollers brand have been utilized.

It may also imply that the academic search engine did not find the needed data in this study. The inclusion and exclusion criteria may sound strict.

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DECLARATIONS

Conflict of Interest

The researcher declares no conflict of interest in this study.

Informed Consent

I have read and understand the provided guidelines in this journal publication. I am fully knowledgeable about this publication including all its rules and regulations.

Ethics Approval

I declare adherence to the accepted ethical standards.

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APPENDIX A

REFERENCE ENTRIES FOR SELECTED PAPERS

Table 2. Summary of Studies

Number	Titles	Authors
1	Low-Cost Air Quality Monitoring System for the Local Government Units of the Province of Rizal	Pacis, J. M. C.
2	LoRaWAN-based Air Particulate Monitoring System	Ellares, A. S., & Linsangan, N. B.
3	Fruit-drying during the pandemic: Designing Raspberry Pi-based smart roof mechanism for food preservation	Romero, C. N., Neyra, R. Q., & Recto, K. H. A.
4	Design of autonomous sensor nodes for remote soil monitoring in tropical banana plantation	Tiausas, F. J. G., Macalinao, M. J. M., Guico, M. L., Monje, J. C., & Oppus, C.
5	Low-cost internet-of-things water-quality monitoring system for rural areas	Bogdan, R., Paliuc, C., Crisan-Vida, M., Nimara, S., & Barmayoun, D.
6	Automated Dual-Source Squid Dryer with Image Processing Monitoring	Dumaguit, F. A. M., Cañete, L. A. R., Rivas, B. L., Plando, R. A., Mag-Usara, A. E., & Solloso, M. C.
7	A Smart-home Electronic-Nose for Detecting Hazardous Gases	Moustafa, K. H., Metawie, H., Hany, A., Ehab, A., Sherif, O., & Saed, O.
8	SIMILARITY Application of Internet of Things (IoT) on Microclimate Monitoring System in The ALG Unpad Greenhouse Based on Raspberry Pi	Nurpilihan, B., Ardiansah, I., & Asmara, S.
9	Development of a Platform for Monitoring the Levels of Dispersed Oxygen in River Components of a Water Supply Micro Basin Using Programmable Microcontrollers	Sakiyama, R. Z., Zukeram, E. S. J., Ruiz, L. B., & Andrade, C. M. G.
10	Smart Irrigation Framework Using Arduino for an Improved Abaca Farming System	Salazar, E., & Morales, A.
11	Intelligent Aeroponic System for Real-Time Control and Monitoring of Lactuca Sativa Production	Calzita, C. R., Jubilo, K. A., Permejo, G., Reas, R., Baun, J. J., Concepcion, R., Bandala, A., Mayol, A., Vicera, R., & Dadios, E.
12	Automated People Counter for Restricted Capacity Monitoring on Philippine Public Utility Bus	Chan, J. N. M., Guico, M. L. C., De Guzman, C. G. P., & Galicia, J. K. A.
13	Initial Performance of the Upgraded ASTI arQ Data Logger for Monitoring Environmental Parameters	Orejudos, J. M., Javier, J. C., Paler, H. B. S., Dellagas, A. A. P., Badong-Carlos, J., Guba, G. P., Mosquera, I. C. & Cureg, C. S. A.
14	Proposal of a New System for Essential Oil Classification Based on Low-Cost Gas Sensor and Machine Learning Techniques	Viciano-Tudela, S., Parra, L., Navarro-Garcia, P., Sendra, S., & Lloret, J.

15	Efficient Utilization of Traffic Lights in Common Congested Areas in Urban Settings Through Crowdsourcing	Villaluz, A. J. A.
16	Effects of low humidity and high humidity on the nasal area of the people	Arcenal, K. V. R., Carmen, M. S., & Garcia, R. G.
17	Precision Controlled Ventilation Using Ambu Bag For Machine Learning Dataset Creation	Kumar, A., Vishnu, P., & Tasnin, W.
18	Low-Cost Water Quality Sensors for IoT: A Systematic Review	de Camargo, E. T., Spanhol, F. A., Slongo, J. S., da Silva, M. V. R., Pazinato, J., de Lima Lobo, A. V., Coutinho, F. R., Pfrimer, F. W. D, Lindino, C. A., Oyamada, M. S., & Martins, L. D.
19	Identification of Herbaceous Plants with Electronic Nose using Fuzzy Logic Algorithm	Armada, E. G., & Manlises, C. O.
20	IoT-Based Conceptual Framework for Baler Waste Disposal Management System	Glorioso, S. B.
21	Development of IoT Based Temperature, Humidity, and Substrate pH level Control System for Oyster Mushroom (Pleurotus Spp.) Cultivation	Conde, C. V. D.
22	Design and Development of Remote-Controlled Boat with GPS Navigation for Water Quality Measurements	Miranda, J. P. S., Villadelrey, V. V., & Cruz, F. R. G.
23	Development of an IoT-Based Soil Macronutrient Analysis System Utilizing Electrochemical Sensors and Machine Learning Algorithms	Amado, T. M., Alvarez, A. E. D., Ocampo, A., Paz, V. A. F., Punongbayan, A. J. N., Lemuel, M., Yumena, Padilla, M. C., Madrigal, G. A., Tolentino, L. K., & Monilar, E. G.
24	An Open-Source, Low-Cost Apparatus for Conductivity Measurements Based on Arduino and Coupled to a Handmade Cell	Visco, G., Dell'Aglio, E., Tomassetti, M., Fontanella, L. U., & Sammartino, M. P.
25	Intelligent Water Quality Management in Maturation Tanks for Penaeus Monodon Using Fuzzy Logic	Chua, A., Imperial, E. D., Mababangloob, G. R., Tinhay, J. B., & Concepcion, R.
26	Development of Earthquake Detection and Warning System Based on Sensors.	Chen, F. H., Shieh, H. L., & Tu, J. F.
27	Review of water quality monitoring using Internet of Things	Choudhury, T. A., Kandra, H. S., Dinh, K., & Lim, S.
28	Smart Aquaponics System for Oreochromis niloticus Production	Egnalig, C. J., Jamero, O., Tampong, A. P., Bacarro, R., Dumaguit, F. A., & Cañete, L. A.
29	Review on the Real-time Implementation of IoT-enabled UAV in Precision Agriculture and the Overview of Collision Avoidance Strategies	Ganesan, T., Jayarajan, N., & Sureshkumar, P.
30	Implementation of a Data Acquisition Tool for Sensor Measurements	Nylund, C.
31	Ion-Mobility Spectrometry–MQ5 Sensor System for Gas Refilling Stations	Yumang, A. N., Lazaro, J. B., Ongpauco, J. N. A., Solis, M. V., Aquino, J. J. M., & Cruz, J. D. R.

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33	SMART Bins–The Next-Gen Segregation and Data-Relay Revolution	Celestial, H. V. B., De Luna, R. M. P., Navarette, M. A. S., Lat, R. C., & Destreza, F. G.
34	Prediction of Oxygen Consumption in Milkfish Larvae using Single Exponential Smoothing Method in Edge Device	Hamid, H. P., Niswar, M., & Paundu, A. W.
35	SmartHatch: An Internet of Things–Based Temperature and Humidity Monitoring System for Poultry Egg Incubation and Hatchability	Maaño, R. C., Maaño, R. A., De Castro, P. J., Chavez, E. P., De Castro, S. C., & Maligalig, C. D.
36	Building the bridge to a participatory citizenship: Curricular integration of communal environmental issues in school projects supported by the internet of things	Santos, M. J., Carlos, V., & Moreira, A. A.
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40	IoT solutions for smart farming: A comprehensive review on the current trends, challenges and future prospects for sustainable agriculture	Ha, C. D., Minh, P. T., Van Tien, T., Thu, P. P., & Trien, P. M.
41	Implementation of an IoT-Based Car Park Availability Monitoring System	Navarro, J. D. P., Punla, R. M. H., & Agustin, L. L.
42	Water circulation and control of hydroponics using the Internet of Things	Morite, A. S., Bacarro, R. R., Gamboa, G. Z., Angob, V. J. V. D., & Manzo, E. J. M.
43	Improving Rice Farming Productivity through Solar-Powered Electronic Stirring with SMS Notifications	Destreza, F. G., Buenas, L. J. E., & Atienza, E. A. V.
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49	Scheduling and predictive maintenance for smart toilet	Lokman, A., Ramasamy, R. K., & Ting, C. Y.

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51	Effects of Different LED Light Compensation on Lettuce (Lactuca Sativa) on Hydroponics System Using Easy Method Leaf Area Estimation for Growth Monitoring	Viste, S. R., Dimayacyac, A. M. F., Hortinela, C. C., & Fausto, J. C.
52	Remote monitoring of a mesh network fire system	Santos, A. D. S., Paloma, E. F. H., Doroteo, A. R. J., Dimaunahan, E. D., & Ballado, A. H.
53	Implementation of GSM Module based Smart Aquarium Monitoring and Controlling System	Sohail, M., Prasad, M. V., Vamshi, S. K., Chandu, S. M., Tripathi, S. L., & Madhavi, K. B.
54	Smart e-waste management system utilizing Internet of Things and Deep Learning approaches	Voskergian, D., & Ishaq, I.
55	Remote control and monitoring of a solar water pumping system using cellular network for Sukkur Pakistan	Ahmed, O.
56	AI based Plant Growth Monitoring System using Computer Vision	Bhamare, A. Upadhyay, V., Bansal, P.
57	AI-based Leaf Disease Identification Robot using IoT Approach	Nagaraj, P., Rajkumar, T. D., Rakesh, S., Durga, A. K. S., Jyothi, M. L., & Nithin, C. G. S.
58	LoRa-Based Low-Cost Nanosatellite for Emerging Communication Networks in Complex Scenarios	Parada, R., Monzon Baeza, V., Barraca-Ibort, D. N., & Monzo, C.
59	Contactless Weight Monitoring of Grow-out Nile Tilapia in a Recirculated Aquaculture System Using Multiple Linear Regression Supervised Machine Learning Approach	Fiesta, M. M., Mayormente, M. D., & Palaoag, T. D.
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61	Internet of Farming Things and RTOS based Robotic System for Water Quality Monitoring and Fish Feeding in Freshwater Aquaculture	Veeramanikandasamy, T., Babu, P. R., Devendiran, S., & Aravind, N.
62	Ai And Iot Based Irrigation System Using Soil Moisture	Akhare, R.
63	AICanHear: Assistive Alerting Device for Deaf and Hard-of-Hearing People (DHH)	Buhat, R. G. A., Capuno, C. B., De Guzman, R. A. D., Pascua, M. D., Tan, D. J. S., Gallego, M. P., & Noriega, M. E. A.
64	Low-Cost Electronic Nose for the Determination of Urinary Infections	de la Rica-Martinez, A., Martínez-Muñoz, G., Sanjuan, M. A., Conesa-Celdrán, A., Garcia-Moreno, L., Estan-Cerezo, G., Oates, M., Gonzalo-Jimenez, N., & Ruiz-Canales, A.
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66	Development of CNN Model to Avoid Food Spoiling Level	Baswoju, S. P., Latha, Y., Changala, R., & Gummadi, A.
67	A Review to do Fishermen Boat Automation with Artificial Intelligence for Sustainable Fishing Experience Ensuring Safety, Security, Navigation and Sharing Information for Omani Fishermen	Amuthakkannan, R., Vijayalakshmi, K., Al Araimi, S., & Ali Saud Al Tobi, M.
68	Wearable obstacle avoidance electronic travel aids for blind and visually impaired individuals: A systematic review	Xu, P., Kennedy, G. A., Zhao, F. Y., Zhang, W. J., & Van Schyndel, R.
69	Design and implementation of an artificial intelligence of things-based autonomous mobile robot system for cleaning garbage	Chen, L. B., Huang, X. R., Chen, W. H., Pai, W. Y., Huang, G. Z., & Wang, W. C.
70	Smart Sprouts: Fuzzy Logic-Driven IoT-Based Smart Water Management System for Vertical Farming	Kumar, K. A., Metan, J., Hemanth, R., Akash, N., & Sanjay, N.
71	RFID Attendance System-Enabled Automated Hand Sanitizer Dispenser using IoT	Kaveri, K., Jervila, R., Alhaseena, K. M., & Naskath, J.
72	Drip Irrigation Leakage Control using IoT	Mahindhar, K. S., Prasad, K. S., & Ashok, S.
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74	Descriptive Analysis on Data of Stingless Bee IoT Application Monitoring System	Rohafauzi, S., Kassim, M., Ja'Afar, H., Rustam, I., Miskon, M. T., & Pakhrudin, N. S. M.
75	Collection of plastic bottles by reverse vending machine using object detection technique	Yaddanapudi, S. D., Makala, B. P., Yarlagadda, A., Sapram, C. T., Parsa, S. T., & Nallamadugu, S.
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78	Leveraging Fog Layer Data Prediction Using Deep Learning for Enhanced IoT Sensor Longevity	Putra, M. A. P., Abisado, M., & Sampedro, G. A.
79	Omni-Directional Sorting Conveyor	Abu-Radeh, Y., Shahateet, N., & Tarwa, S.
80	Real-time soil monitoring and irrigation system for taro yam cultivation	Rahim, A. A., Mohamad, R., Shuhaimi, N. I., & Buclatin, W. C.
81	Mechanizing Indian Agriculture with precision farming technologies: Challenges and perspective	Agrawal, K. N., & Bangale, R. A.
82	A Survey on Internet Of Things Based Smart Bin	Jonuzi, V. M., Mishkovski, I., & Chorbev, I.
83	A critical review on efficient thermal environment controls in indoor vertical farming	Ahamed, M. S., Sultan, M., Monfet, D., Rahman, M. S., Zhang, Y., Zahid, A., Bilal, M., Ahsan, T.M., & Achour, Y.
84	Design and Development of Automated Indoor	Chua, Y. L., Bharuddin, S. M. F. M., & Koh,

	Farming with Alert System	Y. Y.
85	Sustainable Smart Agriculture Farming for Cotton Crop: A Fuzzy Logic Rule Based Methodology	Bin, L., Shahzad, M., Khan, H., Bashir, M. M., Ullah, A., & Siddique, M.
86	Emerging Technologies Transforming the Future.	Prasad, M. D., Vejendla, M., Sai, N. R., GUPTHA, K. G., & REDDY, P. D. K.
87	Development of a modular agricultural robotic sprayer	Sanchez, P. R. P.
88	Design and Simulation of a Trans-Impedance-Based Instrumental Circuit for Weevil Repelling	Awal, M. A., & Ahsan, A. N. M.
89	Designing and Implementation of Power Converter for Solar Pump to Drive Agriculture Load	Bansal, S., Patel, R. N., Nigam, M. K., Victor, V. M., & Kishor, Y.
90	Adaptive Neuro-Fuzzy Inference System-Based GPS-IMU Data Correction for Capacitive Resistivity Underground Imaging with Towed Vehicle System	Dadios, E., Baun, J. J., Enriquez, M. L., Janairo, A. G., Concepcion II, R., De Leon, J. A., Francisco, K., Mayol, A. P., Bandala, A., & Vicerra, R. R.
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92	Smart Irrigation Systems in Agriculture: A Systematic Review.	Vallejo-Gomez, D., Osorio, M., & Hincapie, C. A.
93	Determination of productivity, yield and bioactivity of propolis extract produced by Tetragonula spp. Cultivated in Modular tetragonula hives	Abduh, M. Y., Ramdhani, F., Setiawan, A., Rifqialdi, G., Rahmawati, A., & Zainudin, I. M.
94	Spatial distribution of soil nutrient content for sustainable rice agriculture using geographic information system and Naïve Bayes classifier	Yudhana, A., Cahyo, A. D., Sabila, L. Y., Subrata, A. C., & Mufandi, I.
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97	Prediction of Whiteleg Shrimp Feed Requirement Using k-Nearest Neighbours Regression	Syarief, M.
98	Evaluation of a Wave Powered Water Pump Performance by Ocean Field Testing and WEC-Sim Modeling	Kimball, C.
99	Fine-grained Haptics: Sensing and Actuating Haptic Primary Colours (force, vibration, and temperature)	Abad, A. C.
100	Face Mask Detection Using Artificial Intelligence	Raj, B., Devi, M., & Raj, B.
101	Thermal transfer and temperature reductions from shading systems on opaque facades: Quantifying the impacts of influential factors	Shah, I., Soh, B., Lim, C., Lau, S. K., & Ghahramani, A.
102	Current landscape and future directions of synthetic biology in South America	Gomez-Hinostroza, E. S., Gurdo, N., Alvan Vargas, M. V. G., Nikel, P. I., Guazzaroni, M. E., Guaman, L. P.,

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105	Thinking through making: Crafting technology for textiles	Kocak, C., Gulbaba, M., Ozden Yenigun, E., Ozsoy Sagnak, O., & Tutuncuoglu Demir, M.
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107	Automatic Fish Feeder and Telegram Based Aquarium Water Level Monitoring	Dewantara, B., Sulistiyowati, I., & Jamaaluddin, J.
108	Hydroponic Agriculture with Deep Learning and Machine Learning Methods	Bulut, N., & Hacıbeyoglu, M.
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Appendix B
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