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FLOOD MONITORING AND WARNING SYSTEMS: A BRIEF REVIEW

洪水監測和預警系統：簡要回顧

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Abstract

Floods and excessive rainfall are unavoidable phenomena that can cause massive loss of people's lives and destruction of infrastructure. Flash floods rise rapidly in flood-prone areas, resulting in property damage, but the impact on human lives is relatively preventable by the presence of monitoring systems. Although there are many systems widely in practice by disaster management agencies in monitoring flood levels, most of these systems are limited range and sophisticated to be used and maintained. Furthermore, in most developing countries, the conventional flood gates in water canals are manually operated and suffer from the lack of real-time monitoring of water levels, leading to an overflow in the channels and flash floods. On top of that, the lacking accurate data analysis in the system that can be accessed is one of the limitations of the conventional flood monitoring and warning systems (FMWS). Therefore, in this paper, we have explored and reviewed the existing methods of flood monitoring and emphasizing their structure and sensing techniques. We have also classified and compared their advantages and limitations and accordingly suggested new solutions and improvements by utilizing new technologies based on the Internet of Things. This paper introduces a detailed mini-review of sensing methods in the existing flood systems as reported in previous studies to serve as a quick guide to researchers who are engaging in this field. Based on the review, conclusions have been drawn.

Keywords: Flood Phenomena, Intelligent Systems, Internet of Things, Monitoring System, Sensing Method

摘要 洪水和過量降雨是不可避免的現象，會造成大量人員傷亡和基礎設施破壞。洪水易發地區的山洪暴發迅速上升，造成財產損失，但通過監測系統的存在，相對可以避免對人類生活的影響。儘管災害管理機構在監測洪水位方面有許多系統在實踐中廣泛應用，但其中大多數係統的範圍有限且使用和維護複雜。此外，在大多數發展中國家，水渠的常規防洪閘門是手動操作的，缺乏實

時監測水位，導致運河溢流和山洪暴發。最重要的是，無法訪問的系統中缺乏準確的數據分析是常規洪水監測和預警系統（FMWS）的局限性之一。因此，在本文中，我們探索和回顧了現有的洪水監測方法，並強調了它們的結構和傳感技術。我們還對它們的優勢和局限性進行了分類和比較，並相應地提出了新的解決方案和改進方案，並利用基於物聯網的新技術進行了改進。為從事該領域的研究人員提供快速指南。基於審查，得出結論。

关键词: 洪水現象, 智能係統, 物聯網, 監視系統, 感應方式

I. Introduction

A flood is a natural disaster that contributes to a huge problem, especially in this electronic world since it is a water-type disaster [1]. A flood is an event where there is a massive increase in the water level in an area. With all the effects, the impact on human life is relatively preventable [2]. In such phenomena, an abnormally high-water level suddenly exists in a supposedly dry place—seasonal rainfall, typhoon, and tsunami some examples of natural causes for flooding. However, for flash floods, the inconvenient drainage and the un-planed structure that could block the water flow are the most common factors that trigger it. For permanent and sustainable riverine flood risk management, complicated engineering techniques are applied. For example, building dams, artificial levees, wing dikes, channel straightening, and diversion spillways. The barriers in controlling floods by block and store the floodwater for a period. Levees create a wall that prevents the river water from flowing out of its track. While dikes are the partial barriers generally placed approximately perpendicular to the riverbanks to slow down the flow. A channel straightening refers to the artificial shortening of the routes by removing the meanders and making them straight. River diversion refers to the diversion of the river entirely or partially from its natural direction of flow [3]. Moreover, the soft engineering techniques are stressing wet-area improvement such as Floodplain, wetlands restoration, afforestation, and restoring the river to increase the wetlands. Furthermore, all these techniques required many changes, costs, and proper planning for a significant case reduction.

The flood can be classified into three categories; Fluvial Flood, Pluvial Flood, and Coastal Flood. The fluvial flood occurs close to moving water sources such as rivers and streams. Such floods occur due to the sudden increase in the water flow rate and blockage of water flow [5]. When the rainfall is more than usual, the water from the river can overflow from the bank to the nearest area. Therefore, rain is the primary benchmark for determining the starting of fluvial floods. The un-planned water discharged from dams also one of the contributions for the flood to occur.

Figure 1. Flood risk in Malaysia [4]

Nevertheless, this event rarely happens with modem technology and knowledge. Next, the pluvial flood is a flood caused by heavy rain. Unlike the fluvial flood, this type of flood occurs at random places include the city and rural areas. The worst-case scenario is a flash flood. The damage toward humans does not form the water but forms the debris carried out by the water. The seasonal wind sometimes creates a windstorm, and when it combines with massive rainfall, it can create an instant flood or flash flood. The unplanned flash flood occurs during drainage or river maintenances, enlargement, and closes. This flood may happen in rapidly growing cities like Kuala Lumpur – Malaysia [6, 7]. Lastly, a Coastal flood is a type of flooding event where the area affected is the seashore and swamp area [8].

The flooding event causes intense storm surges, seasonal winds, and tsunamis. When high tide occurs during this event, it is resulting in a catastrophic storm surge flood. The damage impacts the fisherman's economy for several months, hence decreasing the shortage of fish supply. On top of that, Malaysia experiences two monsoon winds every year. The Southwest Monsoon from late May to September, and the Northeast Monsoon from October to March. The Southwest Monsoon indicates the dry season since its origin from the deserts of Australia. The

Northeast Monsoon, which comes from China and the North Pacific, contributes more rainfall to Malaysia than Southwest Monsoon.

As for Malaysia, most natural disasters such as volcano eruptions, hurricanes, and significant earthquakes did not occur due to its geographical location outside the 'Pacific Rim of Fire'[9]. However, flood is a big challenge and has a significant impact on this country. The country experiences flooding annually. It is responsible for fatality, disease spread, and other losses and damages. Not only that, but Malaysia is also involved in all three types of flooding; Fluvial flood, Pluvial flood, and Coastal flood. First, a fluvial flood is a rare event that can occur. However, once it starts, the effect can be catastrophic since most cities in Malaysia are built either on or close to the main river, such as Kuantan and Kuala Lumpur. As a developing country, flooding is usually in close relation to the drainage problem and heavy rain. The difference between the pluvial and fluvial floods is the location of the occasion. If the flooding has river overflow, it is fluvial floods [10], whereas the pluvial floods create a temporary lake that can stand for several days or weeks. As for the coastal flooding, the country, especially on the east side of Peninsular Malaysia, experiences a monsoon season that usually occurs from October to March and peaks in November and December. During this peak, the rainfall frequency is high, and it led to multiple flooding events.

In general, the flooding has psychological effects on the people, especially those who live in flood-prone areas and have no other alternative except to stay and live with it. The impact on the personal and government in term of the economy are considerable. The agriculture sector is badly disrupted since the water submerges the croplands. The flood may wash away the crops. The recovery of the farm is not an issue, but the waiting time for the land to dry or useable can impact personal finances. The flood positively impacts the farmer in a short period only while the manufacturing suffers a negative growth for short and long terms. As the disease spreading through the floodwater, the chance for animals to get infected is high, especially the livestock. The impact on both the Agriculture and Manufacturing sectors during flooding crises can impact the country's Gross Domestic Product. Therefore, the flooding disaster needs to be taken seriously.

Floods can be detected and observed with the help of the Flood Monitoring and Warning Systems (FMWS) that increase the people's awareness in that area and warn them about the flooding event. Thus, improving people's survivability while decreasing overall damage. Real-time flood monitoring systems have not been investigated in-depth, especially in developing countries, including Malaysia. With the emergence of new wireless technologies and the Internet of Things (IoT) paradigm and applications[11-17], the development of IoT-based FMWS becomes a real need for enabling the real-time monitoring of floods in catchment areas and disseminated information about flood threats to the public. Therefore, conventional flood monitoring systems should be replaced with real-time data systems that utilize new technologies in flood management to minimize the impact of flooding and overcome the existing limitations.

This paper reviews the existing flood sensing methods to highlight their limitations and suggests future directions to mitigate the conventional systems' challenges and increase people's awareness of floods in their areas via real-time monitoring systems. Sensors are the key players in detecting, measuring, and translating environmental data into digital data. Therefore, it is essential to consider what type of information that is required to detect the flood.

The remainder of this paper is organized as follows. Section II presents an overview of FMWS. Section III describes the sensing methods and the utilized sensors in the existing systems. Finally, Section IV concludes remarks and highlights directions for future work.

II. FLOOD MONITORING AND WARNING SYSTEMS

Flood is an unavoidable phenomenon that might cause massive loss of people's lives and destruction of infrastructure. Recently, the existence of FMWS reduces the impact of floods on human lives. Different systems are widely in practice by disaster management agencies worldwide to monitor flood levels. However, most of these systems require high installation and maintenance costs. The main goal is not to stop or prevent the flooding but to increase the people's awareness in those areas and warn them about the flooding event. Thus, it will increase survivability while decreasing electronic damage. Such FMWS system function is to act as an early warning or a real-time alerting system for assisting the civilians to be alerted by the flood level that endangers them. However, these systems have their constraints that need to be taken into consideration for future FMWS improvements.

The Advanced Very High-Resolution Radiometer (AVHRR) is one of the satellite features compatible with the remote flood monitoring system. For example, China had used multiple satellite data sources to identify the flood area and determine the degree of severity by determining the water surface friction. In India [18], Synthetic Aperture Radar (SAR) satellite data and Geographic Information System (GIS) helps to identify the flood flow and progression during the flooding event. Both systems took advantage of satellite radar in their FMWS. The FMWS device development is a stand-alone device that focuses more on flood monitoring functions. It composes both software and hardware tools. As shown in Figure 2, there are three types of FMWS device development; manual, remote, and prototype/amateur. The manual FMWS devices require human interaction to monitor and operate the system continually. Floodgates are great at managing and controlling flooding. It also helps to prevent and manage the water supply in the river and carnal [19]. Common floodgates in Malaysia are manual operated, which needs the operator to continually supervise the water level if in any circumstances that the operator is not available or unaware of the level, leads to halt of river flow that would cause an overflow in the canal [20]. Now, the floodgates had several varieties; manual, semi-automatic, and automatic.

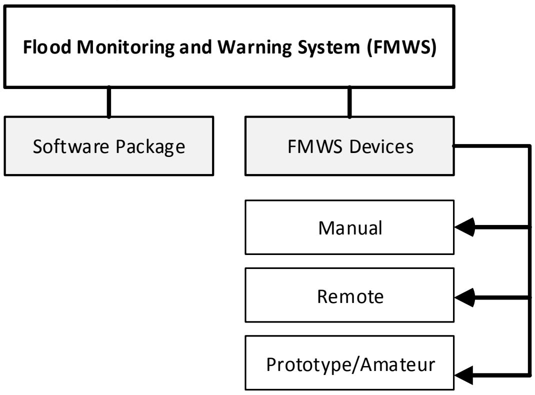

Figure 2. Classification of FMWS

Remote FMWS devices are automatic devices that are placed to monitor the targeted area. All the information regarding the flooding events is updated from time to time. The devices prevent or reduce the flooding cases, but it more to alert the resident and the rescue team before the situation worsens. The devices are equipped with communication technology, sensing, and power supply. Some devices use the GSM module as their communication system between the device and the reception via SMS. ZigBee/IEEE 802.15.4, on the other hand, allows the data to be uploaded and monitor online [21, 22]. Other devices utilize Wi-Fi as their communication medium, which is limited to the Wi-Fi range.

With the emerging IoT paradigm, several communication technologies are used to implement IoT applications such as LoRa, Narrowband IoT, Sigfox, LTE, and 5G [23]. The remote FMWS systems have either multiple sensing nodes or a single sensing node. Both have the same function, but the complexity of the network needs to be considered. The goal of this device is to eliminate the human presence in the monitoring process. Some devices require a direct power supply [21], while others need add-on solar power as their backup power [24]. The distance from the mainland or power source is one of the criteria determining the type of power source.

The last type of FMWS device is the prototype or amateur FMWS device. It is a minor or mini-project conducted to study the process and a starter for a complete machine. This device is not undertaking a field test. Instead, it was tested in an immediate and controllable environment. For example, the author of [25] used a water level sensor for measuring the depth/level of liquid in a container and send the information through the GSM module. At this level, the connectivity of the mobile connection is high and consistent. The alarm and message will be activated and send to the authorities if the water level reaches a dangerous level. Therefore, the applicability and reliability of such devices may be questionable.

III. Flood Sensing Methods

This section will classify the existing FMWS based on the sensing method and monitoring flood levels. Usually, FMWS consists of sensors to measure the flood level, a controller to gather the data from various sensors, and actuators to triggering alarms and notifications. There are a natural evolution and advancement in sensor technology with the new era of nanotechnology and nanosensors [26-29]. This brief review will focus more on the sensors utilized in the existing systems based on previous studies.

A. Ultrasonic Sensor

An Ultrasonic sensor is used in many applications for measuring distance or sense objects. It uses radio waves as a medium to determine the range or distance between the thing and the sensor. The key is the time taken for the wave to travel and return to the sensor. The advantages of this sensor are that it can detect both metal and non-metal objects, including water. Therefore, some FMWSs integrate this sensor into their system.

In [30], the authors briefly explain the flood monitoring and warning prototype. The device used an ultrasonic sensor, temperature sensor, and humidity sensor for measuring the environment parameter. The microcomputer Raspberry Pi 3 is chosen for the gateway. As for the node, Arduino Uno with GSM Module installed collects the data from the sensors before transferring it to the server or gateway. The GSM also informs the water level update while sending the warning if the water level is high. The server will send the updated data to the FloWS Android Application for online inspection and monitor with a graph. However, the prototype is tested with only one node, and the GSM is limited to the sim coverage. Despite having more than one minute to send the data, the author did not mention the distance that has been tested. For Ref. [2], the authors briefly discuss the implementation of IoT and the flood monitoring system. They used an ultrasonic sensor (HC SR04), Arduino Mega, and GSM modules. The system communicates between sensor nodes, servers, and residents via SMS. There are 11 sensor nodes had been deployed. The target test side is at the Meghna basin, Bangladesh. Throughout the paper, the authors mentioned using the rainfall data, but there is no specified origin. The usage of SMS is not cost-effective since the mobile operator company will charge it.

In [31], the sensors used in the system are ultrasonic and rain precipitation sensors for detecting floods and the weather in the targeted area. The data processing and transmission module installed at a remote site is a GPRS Data Unit (GDU), while the GPRS gateway server is implemented at the control center. The GDU is a sensor node, and it was implemented at 15 remote sites. The sensor network measures the related data while the processing and transmission module transmits the measured data to the database and application server. The web-based application that provides users with views of water condition with ten minutes' interval and end-user can access this system through the web browser. The system will notify system administrators via SMS. The authors of [32] present a cloud-based flood monitoring system. The sensors used to measure the water level are HC SR04 ultrasonic sensor and LL103101 liquid level sensor connected to the Arduino board. The Meghna system is used as a gradient server, while the CloudSim simulation tool is used to design and evaluate the cloud server. Six user bases incorporate sensors in the architecture, with ten requests per user per hour. The average response time for lightly loaded cloud nodes and heavily loaded cloud nodes is around 51 (ms).

[33] proposed a flood warning system using an Ultrasonic sensor HC-SR04 as a sensor to detect water level while processing the information into a microcontroller (ESP8266 NODEMCU). Three LEDs has been operating for warning signal (Red, Green, and Yellow). Even though the microcontroller has a built-in Wi-Fi module, the system will send the information through SMS or telephone calls to notify the public authorities. The system uses the ZigBee interface for wireless communication. The system is never gone through a field test, and its ZigBee has short-range communication and limits up to 100 meters only.

In [34], a flash flood sensor combining ultrasonic rangefinders with passive infrared temperature sensors was developed. This sensor is used for an urban flash flood wireless sensor network architecture since it can monitor pluviometry, water presence, and water level with relatively high accuracy. The authors mentioned that the temperature would affect the speed of sound and thus affect the ultrasonic measurement. A non-model-based approach is chosen for estimating the correction due to deviations in temperature, showing that Artificial Neural Networks capture the effects of the underlying model very accurately. The ultrasonic measures the distance between the sensor and the ground, thus detecting the water presence (not depth). Then, the system reduces the error up to 2 cm even without undergoes stimulation training. However, the system consumes much power for computing. The system is tested for stimulation or Neural Network training. The procedure takes two hours to upload one week of data. The system is not ready for multiple nodes. The information that was uploaded is not for the public.

Authors in [35] briefly describe flood monitoring systems using wireless sensor networks (WSN) and IoT bases. The system consists of N-mote a node, M-gateway, and using Bluemix/ Ubidots cloud for this flood monitoring system. The N-mote and M-gateway have an Xbee module connected to their circuit for communication purposes. The sensor data such as temperature, humidity, rainfall rate, and water level can be sent through Ethernet or Wi-Fi, and it will be in the form of a python script. Moreover, it sends a warning message to the related authorities or government and people's lives in the flood-prone region if necessary.

B. Water Level Indicator

Water level indicators work by using sensor probes to indicate water levels. Sometimes this sensor is also known as a liquid level sensor. The sensor probes are placed in certain areas and triggered by the presence of water. The sensor will give a binary output to the microcontroller unit (MCU). This type of sensor does not require calibration during installation. However, getting an actual reading is almost impossible. In[36], the remote water-level monitoring system (RWMS) consists of a field-sensor module, a base station module, a data center module, and a Web releasing module. The field-sensor module is a sensor that measures the environment, such as a water-level sensor. The base station module is where all computing processes occur. The station consists of MCU, capacitor banks, and serial expansion chips. The capacitor banks correcting the phase shift in providing a constant and stable power supply to the circuit. The acquired data can be transfer to the data center through the GPRS/GSM module. The data center module receives the data and processes it before transfers the data to the cloud for online inspection and real-time monitoring.

In [22], the authors briefly explained the flood monitoring and detection system using a wireless sensor network in Uyo, Nigeria. A ZigBee/IEEE 802.15.4 is used for communication between nodes and gateway. The sensors at the node are temperature, rainfall, humidity, and water level sensors, and the data is sent to the microcontroller (PIC24). Fifteen nodes have been deployed in flood-prone regions. At the gateway, the system raises/sends an alert SMS to the resident of the flood area. However, the system is limited to the urban region. The Zigbee has a shorter range compared to long-range technologies. The warning SMS is not efficient compare to the internet-based dashboard.

In [37], a flood monitoring system that integrates both flow and water level sensors was designed. This system uses a hydraulic pressure gauge meter to measure water pressure and determine the water flow rate. From this rate, the indication of the flood can be determined. A NodeMCU ESP8266 is used as an integrated microcontroller with Wi-Fi embedded in the chip. Ref. [38] describes the usage of the IoT in the flood monitoring system via using Netduino Plus two board as a microcontroller. In terms of sensors, the system uses four wires to measure the height of the water. The prototype has access to the internet to keep updating and monitoring the water level of the area of interest. But the system is not applicable in real situations due to the conventional method in sensing the water level. This system can be considered an amateur flood monitoring and warning system. The usage of wire as a sensor can give a considerable fault warning during raining season. Therefore, the system lacks the actual usable sensor.

[39] described the flood monitoring system based on a wireless sensor network. The system uses only one sensor, the LL Series Liquid Level sensor. And for the communication between nodes and gateways, the author used the X-Bee module. Arduino Ethernet-shield has been used as a microcontroller for the node. The water level data can be observed through the internet. As for the graphical representation, the data is updated at a slower rate (Hourly). The real-time data are tallied with flood mapping. The information is updated for every hour in the table. And for the graph, the data is limited to four hours' intervals, and the map has a color indicator to indicate the water level.

C. Camera

The camera is one of the imaging electronics that are used in the imaging system. The sensors that are responsible for collecting the information from the image are photodetectors. A million discrete photodetector sites collect the light from the image. The pixels may be photodiodes or photo capacitors. And each pixel commonly has different RGB intensity values for each point of the object. In [21], the authors briefly explained previous flood monitoring systems and improved such systems. A system consists of a river depth sensor, camera, and rain gauge to measure and determine the degree of the flood event was proposed. The information from the sensor node is transfer via a ZigBee network and 3G cellular network. Six sensor nodes were deployed along a creek. During heavy rainfalls, the probability of a sensor node failing increases. To overcome this problem, the author uses Unmanned Aerial Vehicles (UAV) or drones to provide support and ensure that the connection is not disrupted by flying over the failed node. The mainboard or the computer is a Raspberry PI 2 model. The system was attached with a camera and a 3G modem. Usage of the drone can add up some costs during deployment.

On the other hand, a flash flood prediction system was proposed in [40]. It requires three components: an infrared camera, a communication interface, and an image processing server. The data from the camera are sent to the server using a 3G module. The server provides real-time water levels with the ability to monitor complex water flow situations. The data will be updated at five minutes intervals. In heavy rain situations, the system can change the calculating interval and measure the water level and riverbank height in one-minute-based intervals for a 30-minute duration. The unmanned surveillance system for observing water levels [41] is a low-cost unmanned surveillance system consisting of remote measuring stations, and a monitoring center uses a map-based Web service. The water level is measured by counting the pixels based on the measuring ruler. Before entering the actual test, the algorithm required training procedures and deep learning to differentiate between the ruler and the water body. It can increase the time and accuracy of the system for measuring the water level. The computer provides a real-time and historical water level, and the data can be stored online. But the convolutional neural network (CNN) requires complex calculations.

Furthermore, the video camera can shake slightly for the wind blow. Therefore, this system requires a constant re-calibrate of the sensor or the parameter. In measuring the depth of liquid, the water level is directly proportional to the pressure [42]. Therefore, this technique is commonly used on tanks and submarines for determining the water level or depth. The approach is alerting the residents about the upcoming flood event via SMS. The system used an Arduino board as a microcontroller and the pressure sensor (MPVZ5010G7U) for measuring the water level. These systems are lacking in terms of reliability for sustain in a long time. On top of that, the usage of the GSM module is limited via cellular coverage and can be pretty costly in total.

D. Optical Remote Sensing

When the sunlight hits the ground, the light or radiation can be absorbed or reflected in space. Those reflections can be observed and sensed by optical remote sensing using visible, near-infrared, and short-wave infrared sensors. The reflection from each material is different, as shown in Figure 3. Therefore, by relying on the sensor's output, the object can be easily identified, such as clear water, bare soil, and vegetation. However, this technology can only be deployed using satellites. Landsat initiated the revolution in moderate-resolution Earth remote sensing in the 1970s. In addition, it operates in visible, near-infrared, and infrared spectrums for observing the ground. The Landsat provides a temporal optical image processed and filtered to reduce the atmospheric effect like cloud or mist [43]. Two flood detection algorithms or more are usually being used for a better post-mortem flood analysis. By comparing different sources for flood detection, the result of flood maps is more compiling, and the optical sensor limitation can be removed or eliminated [44].

Moreover, currently, Advanced Very High-Resolution Radiometer (AVHRR) and, more recently, Moderate Resolution Imaging Spectroradiometer (MODIS) data are widely used for flooded areas monitoring and mapping. A high spatial and temporal resolution is perfect for data analysis in making a flood map. The integration between AVHRR and MODIS produces big data, double compared to AVHRR alone. The cloud effect can be filtered easily by implementing both differences and ratio analysis between visible and near-infrared. The observable data came from AVHRR, and the near-infrared are from MODIS channel 1. The decision is made based on the tendency of the sensor. By setting one pixel to represent one km area, the area of interest is comprehensive but accurate enough to detect waterbody alongside the river. Aside from using multiple analytical analyses, the cloud present can be seen with a combination of data from various satellites with relatively different sensor angles[45]. As a result, the analysis increases the system's accuracy to detect the water body while the MODIS can provide more accuracy, especially at 250 m spatial resolution.

E. Lagrangian Sensor

A Lagrangian method is a method to determine the general coordinates, time, and information about the changing aspects of the system. The Lagrangian sensor is designed to operate with a WSN for detecting the flood flow, and during the field tests, the author has confirmed that it has a range up to 100 m for normal conditions and up to 50 meters for half immersed in water[46]. This sensor senses the water flow by gliding with the water. As shown in Figure 4, there are two types of nodes employed in the network. The first one is a sensing node, and a fixed receiver tracked their locations, and the data is sent to the network server. The second is the relay node for relaying data or repeating signals. The sensor node comprises a transmitter and integrated microcontroller or printed circuit paper (PCP). The node has a unique identification (ID) for a tracked purpose using the CC2530 transceiver for communication. Therefore, the user can get the flood flow velocity and direction of flood flow. The system does not use any water sensing to Sense the presence of water. However, the sensor cannot detect multiple nodes at the same time. The usage of the CC2530 transceiver has a shorter range, and the system only suitable for drainage and open space. Lastly, this Lagrangian must be reset and reposition the sensing devices every time to reuse the system.

F. Radar Systems in Flood Monitoring

Radio detection and ranging, or radar, is used for remote sensing and deployed either on the ground or satellite. In satellite, a Synthetic Aperture Radar, SAR is a powerful microwave instrument used to obtain images of the Earth. In addition, the SAR can continue to operate even without Sun radiation, which is an advantage for monitoring the weather such as typhoons, rain, and flood aside, providing navigation and geological analysis or mapping. Ref. [47] developed a near-real-time flood mapping using a very high-resolution RADARSAT-2 sensor for rural and urban areas. The near-real-time data comes from satellite radar images and form a flood map along with water levels in excellent resolution. At first, the photos from RADARSAT-2 determine the location of flooding and the water height. Then, the topographic data is added to increase the accuracy of the data compared to the actual event. The accuracies obtained are 97% and 87% in the rural area and urban area, respectively. With information from hydraulic and satellite images, the impacts of flooding can be analysis and a prediction can be made. As a result, a 3D model of estimation impact of flood for each building with technical information like water level and other elements are created and can be generated artificially.

The Advanced Microwave Scanning Radiometer for the Earth Observing System, AMSR-E, is a multi-channel passive microwave radiometer that observes water-related geophysical parameters [48]. AMSR-E is capable of keeping water vapor, precipitation, and soil moisture. The algorithm, wet surface friction, based on the Soil Moisture Active Passive (SMAP) radiometer data, can detect soil wetness and flood patterns [49]. A low-frequency microwave radiometer is a crucial characteristic of SMAP satellite for precise detecting the surface water even with thick cloud conditions and under low-to-moderate vegetation cover. This detection is possible since land, lake, and ocean had different brightness temperature characters for each pixel.

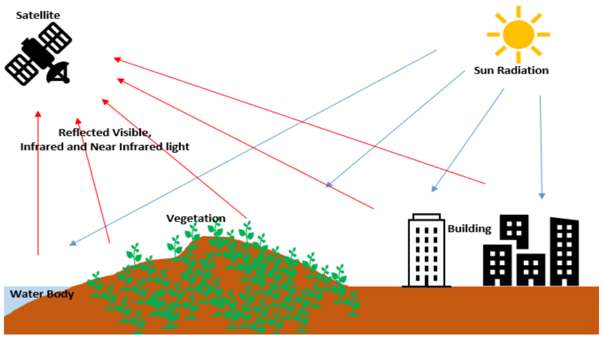

Figure 3. Basic concept of optical remote sensing

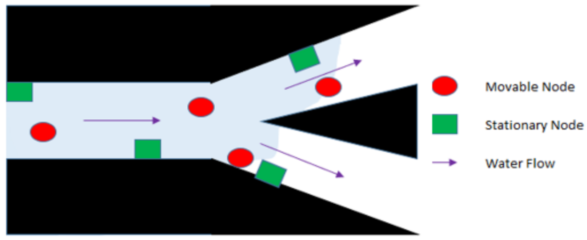

Figure 4. Illustration of Lagrangian sensing method

IV. Conclusion

In this paper, the utilized sensors in the existing FMWS have been reviewed. Each FMWS system has its specific requirements, which lead to a particular choice of sensor. Although there are many systems widely in practice by disaster management agencies for monitoring flood levels, these systems differ in terms of the sensing method, microcontroller, and communication technology. Most of these systems are restricted according to the telecom coverage and sophisticated to be used and maintained. Therefore, a user-friendly flood monitoring and warning system can be achieved based on the new IoT technologies. With the utilization of IoT, information about flood levels can be disseminated everywhere at every time. Thus, increasing people's awareness about the flood. In future work, we will develop an IoT-based FMWS by utilizing the most recent communication technologies to overcome restricted communication range and the most suitable sensor to measure water level and incremental flood rate. A suitable microcontroller will be utilized to develop smart sensing nodes with a wireless interface.

Overall, previous works have covered various environmental monitoring sensor networks, including flood detection systems. According to application nature and location, several types of sensors for data collection are involved in such networks. Some applications focus on rain monitoring, whereas others apply river gauging, where some parameters must be observed and compared. Despite the considerable research on flood monitoring using WSNs, utilization of IoT technology remains a new and emerging field in disaster management. Using such powerful technology to provide real-time information about floods will be a real advance in this field.

Therefore, we will design and fabricate an innovative and user-friendly flood monitoring and warning system as future work. The proposed FMWS exploits an ultrasonic sensor with an Arduino microcontroller to measure water level and identify the situation, whether safe, cautious, or dangerous, based on predefined thresholds. The implemented testbed can act as a beacon for alerting individuals and authorities separately in real-time. System effectiveness will be improved to support data reporting from multiple sensor monitoring units simultaneously to a server or cloud storage via a central network gateway. Thus, we aim at enabling the utilization of IoT technology with a wide range of network connectivity. According to the risk with the water level, the system will trigger early flood warnings to the authorities and population to take preventative action.

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REFERENCES

[1] HASHIM, Y., IDZHA, A. H. M. and JABBAR, W. A. (2018) The design and implementation of a wireless flood monitoring system. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, 10(3-2), pp. 7-11. Available from: https://www.researchgate.net/publication/329389934_The_Design_and_Implementation_of_a_Wireless_Flood_Monitoring_System

[2] AHMED, N., GHOSH, S., HASSAN, R. A., GALIB, S. I., AZAD, A. K. and SYRUS, M. A. (2017) A gradient sensing middleware to handle flash flood. *Computers & Electrical Engineering*, 62, pp. 44-52, https://doi.org/10.1016/j.compeleceng.2017.08.006

[3] NOYMANEE, J., NIKITIN, N. O. and KALYUZHNAYA, A. V. (2017) Urban pluvial flood forecasting using open data with machine learning techniques in Pattani Basin. *Procedia Computer Science*, 119, pp. 288-297 https://doi.org/10.1016/j.procs.2017.11.187

[4] NARATHIP, S. and CLAUDIO, S. (2019). *Understanding Flood Risk in Malaysia through Catastrophe Modeling*. Available from: https://www.brinknews.com/19987

[5] LOMBARDI, A., COLAIUDA, V., VERDECCHIA, M. and TOMASSETTI, B. (2021) User-oriented hydrological indices for early warning systems with validation using post-event surveys: flood case studies in the Central Apennine District. *Hydrology and Earth System Sciences*, 25(4), pp. 1969-1992. https://doi.org/10.5194/hess-25-1969-2021

[6] NORASHIKIN, S., RABIEAHTUL A.B., and TANOT, U. (2018) Flash flood impact in Kuala Lumpur – approach review and way forward. *International Journal of the Malay World and Civilization*, 6(1), pp. 69-76. https://doi.org/10.17576/jatma-2018-06SI1-10

[7] HONG J. L., and HONG, K. A. (2016) Flood forecasting for Klang River at Kuala Lumpur using artificial neural networks. *International Journal of Hybrid Information Technology*, 9(3), pp. 39-60. https://doi.org/10.14257/ijhit.2016.9.3.05

[8] WONG-PARODI, G., FISCHHOFF, B., and STRAUSS, B. Resilience vs. adaptation: Framing and action. *Climate Risk Management*, 10(C). https://doi.org/10.1016/j.crm.2015.07.002

[9] SULAIMAN, S. (2019) Is Malaysia located in the pacific ring of fire? A Legal perspective. In: *ICLES 2018 - International Conference on Law, Environment and Society Law & Nature, Bangi, Selangor Malaysia, 13-16 November 2018.* Bangi: Universiti Kebangsaan, Malaysia, Faculty of Law, pp. 181-190. https://doi.org/10.15405/epsbs.2019.10.20

[10] SCHANZE, J. (2018) Pluvial flood risk management: an evolving and specific field. *Journal of Flood Risk Management*, 11(3), pp. 227-229. https://doi.org/10.1111/jfr3.12487

[11] JABBAR, W. A. (2020) Mobility-based performance comparison of MBQA-OLSRv2 and MBMA-OLSRv2 routing

protocols. In: *Proceedings of 2019 23rd International Computer Science and Engineering Conference (ICSEC), Phuket, Thailand, 30 October -1 November 2019*. Piscataway, New Jersey: IEEE, pp. 281-286: https://doi.org/10.1109/ICSEC47112.2019.8974771

[12] JABBAR, W. A., ISMAIL, M., NORDIN, R. and RAMLI, R. M. (2017) EMA-MPR: Energy and mobility-aware multi-point relay selection mechanism for multipath OLSRv2. In: *Proceedings of 2017 IEEE 13th Malaysia international conference on communications (MICC), at Johor Bahru, Johor, Malaysia, 28 – 30 November 2017*. Piscataway, New Jersey: IEEE, pp. 1-6. https://doi.org/10.1109/MICC.2017.8311721

[13] JABBAR, W. A., RAMLI, R. M., and ISMAIL M. (2020) Comparative performance analysis of MBQA-OLSRv2 and MBMA-OLSRv2 routing protocols MANETs. In: *Proceedings of 2020 International Symposium on Networks, Computers, and Communications (ISNCC), Montreal, Canada, October 20-22, 2020*. Piscataway, New Jersey: IEEE, pp. 1-6 https://doi.org/10.1109/ISNCC49221.2020.9297241

[14] JABBAR, W. A., SAAD, W. K., HASHIM, Y., ZAHARUDIN, N. B., and ABIDIN, M. F. B. Z. (2018) Arduino-based buck-boost converter for PV solar system. In: *Proceedings of 2018 IEEE Student Conference on Research and Development (SCOReD), Bangi, Selangor, Malaysia, 26-28 November 2018*. Piscataway, New Jersey: IEEE, pp. 1-6. https://doi.org/10.1109/SCORED.2018.8710807

[15] JABBAR, W. A., WEI, C. W., AZMI, N. A. A. M. and HAIRONNAZLI, N. A. (2021) An IoT Raspberry Pi-based parking management system for the smart campus. *Internet of Things*, 14(4), p. 100387. https://doi.org/10.1016/j.iot.2021.100387

[16] JABBAR, W. A., YUZAIDI, M. A. B., YAN, K. Q., BUSTAMAN, U. S., HASHIM, B. M. Y., and ALARIQI, H. T. (2019) Smart and green street lighting system based on Arduino and RF wireless module. In: *Proceedings of 2019 8th International Conference on Modeling Simulation and Applied Optimization (ICMSAO), Manama, Bahrain, April 13-15, 2019*. Piscataway, New Jersey: IEEE, pp. 1-6. https://doi.org/10.1109/ICMSAO.2019.8880451

[17] SAAD, W. K., HASHIM, Y. and JABBAR, W. A. (2020) Design and implement the portable smart wireless pedestrian crossing control system. *IEEE Access*, 8, pp. 106109-106120. https://doi.org/10.1109/ACCESS.2020.3000014

[18] RAHMAN, M. R. and THAKUR, P. K. (2018) Detecting, mapping and analyzing of floodwater propagation using synthetic aperture radar (SAR) satellite data and GIS: A case study from the Kendrapara District of Orissa State of India. *The Egyptian Journal of Remote Sensing and Space Science*, 21, pp. S37-S41. https://doi.org/10.1016/j.ejrs.2017.10.002

[19] CHI, S., WEI, C., ZHENG, J., HU, J., LI, M. and HU, J. (2018) Distribution patterns of macroinvertebrate communities in a Chinese floodgate-regulated river and their relationships with river longitudinal connectivity. *Science of the Total Environment*, 631-632, pp. 765-777. https://doi.org/10.1016/j.scitotenv.2018.02.132

[20] DHARSHANA, D., WICKRAMASINGHE, M. and SAMARAWICKRAMA, J. (2017) An automatic control system for sluice gate in salinity and flood control in the open canal. In: *Proceedings of the 28th International Symposium on Transport Phenomena [ISTP28], Peradeniya, Sri Lanka, 22-24 September 2017*. Peradeniya: University of Peradeniya. Available from: https://www.researchgate.net/publication/320880849_An_automatic_control_system_for_sluice_gate_in_salinity_and_flood_control_in_open_canal.

[21] UEYAMA, J., FAIÇAL, B. S., MANO, L. Y., BAYER, G., PESSIN, G. and GOMES, P. H. (2017) Enhancing reliability in wireless sensor networks for adaptive river monitoring systems: Reflections on their long-term deployment in Brazil. *Computers, Environment, and Urban Systems*, 65, pp. 41-52.

https://doi.org/10.1016/j.compenvurbsys.2017.05.001

[22] UDO, E. and ISONG, E. (2014) Flood monitoring and detection system using a wireless sensor network. *Asian Journal of Computer and Information Systems*, 1(4), pp. 2321-5658.

[23] GUILLÉN-NAVARRO, M. Á., PEREÑÍGUEZ-GARCÍA, F. and MARTÍNEZ-ESPAÑA, R. (2017) IoT-based System to Forecast Crop Frost. In: *Proceedings of 2017 International Conference on Intelligent Environments (IE)*, pp. 28-35. https://doi.org/10.1109/IE.2017.38

[24] GUIBENE, W., NOWACK, J., CHALIKIAS, N., FITZGIBBON, K., KELLY, M. and PRENDERGAST, D. (2017) Evaluation of LPWAN technologies for smart cities: River monitoring use-case. In: *Proceedings of 2017 IEEE Wireless Communications and Networking Conference Workshops (WCNCW), San Francisco, CA, USA, 19-22 March 2017*. Piscataway, New Jersey: IEEE, pp. 1-5. https://doi.org/10.1109/WCNCW.2017.7919089

[25] SAGAR, S. V., KUMAR, G. R., XAVIER, L. X., SIVAKUMAR, S., and DURAI, R. B. (2017) SISFAT: Smart irrigation system with flood avoidance technique. In: *Proceedings of 2017 Third International Conference on Science Technology Engineering & Management (ICONSTEM), Chennai, India, 23-24 March 2017*. Piscataway, New Jersey: IEEE, pp. 28-33. https://doi.org/10.1109/ICONSTEM.2017.8261252

[26] MAHMOOD, A., JABBAR, W. A., SAAD, W. K., HASHIM, Y., and MANAP, H. B. (2018) Optimal nano-dimensional channel of GaAs-FinFET transistor. In: *Proceedings of 2018 IEEE Student Conference on Research and Development (SCOReD), Selangor, Malaysia, 26-28 November 2018*. Piscataway, New Jersey: IEEE, pp. 1-5. https://doi.org/10.1109/SCORED.2018.8710811

[27] MAHMOOD, A., JABBAR, W. A., HASHIM, Y. and MANAP, H. B. (2019) Effects of downscaling channel dimensions on electrical characteristics of InAs-FinFET transistor. *International Journal of Electrical & Computer Engineering*, 9(4), pp.2902-2909. https://doi.org/10.11591/ijece.v9i4.pp2902-2909

[28] ATALLA, Y., HASHIM, Y. A., GHAFAR, N. A., and JABAR, W. A. (2019) Temperature Characterization of (Si-FinFET) based on Channel Oxide Thickness. *TELKOMNIKA*, 17(5), pp. 2475-2480. https://doi.org/10.12928/TELKOMNIKA.v17i5.11798

[29] AL ARIQI, H. T., JABBAR, W. A., HASHIM, Y. and MANAP, H. B. (2019) Characterization of silicon nanowire transistor. *TELKOMNIKA*, 17(6), pp. 2860-2866. https://doi.org/10.12928/TELKOMNIKA.v17i6.13084

[30] MARZUKHI, S., SIDIK, M., NASIR, H., ZAINOL, Z. and ISMAIL, M. N. (2018) Flood Detection and Warning System (FLoWS). In: *Proceedings of the 12th International Conference on Ubiquitous Information Management and Communication (IMCOM '18), Langkawi, Malaysia, 5–7 January 2018*. New York: Association for Computing Machinery, pp. 1-4. https://doi.org/10.1145/3164541.3164623

[31] ATIJOSAN, A., SALAU, A. O., BADRU, R. A. and ALAGA, T. (2017) Development of a low-cost community-based real-time flood monitoring and early warning system. *International Journal of Scientific Research in Science, Engineering and Technology, 3(3)*, pp. 189-195. Available from: https://ijsrset.com/IJSRSET173344

[32] AHMED, N., AZAD, A. K., KHAN, M. R., HABIB, A., GHOSH, S., and SHAHID, S., (2016) Shona Bondhu: a cloud-based system to handle the flash flood In: *Proceedings of 2016 International Conference on Networking Systems and Security (NSysS), Dhaka, Bangladesh, 7-9 January 2016*. Piscataway, New Jersey: IEEE, pp. 1-6.

[33] SOUZA, S. A., DE LIMA CURVELLO, A. M., DOS SANTOS DE SOUZA, F. L., and DA SILVA, H. J. (2017) A flood warning system to the critical region. *Procedia Computer Science*, 109, pp. 1104-

1109. https://doi.org/10.1016/j.procs.2017.05.453.

[34] MOUSA, M., ZHANG, X., and CLAUDEL, C. (2016) Flash flood detection in urban cities using ultrasonic and infrared sensors. *IEEE Sensors Journal*, 16(19), pp. 7204-7216. https://doi.org/10.1109/JSEN.2016.2592359

[35] PALLAVI, C. V. (2017) Development of Flood Monitoring System using WSN and IoT based on Cloud. *International Research Journal of Engineering and Technology (IRJET)*, 4(5), pp. 2937-2943. Available from: https://www.academia.edu/33567166/Development_of_Flood_Monitoring_System_using_WSN_and_IoT_based_on_Cloud

[36] RASHID, B., and REHMANI, M. H., (2016) Applications of wireless sensor networks for urban areas: A survey. *Journal of network and computer applications*, 60, pp. 192-219. https://doi.org/10.1016/j.jnca.2015.09.008

[37] ABDULLAHI, S. I., HABAEBI, M. H., and MALIK, N. A. (2018) Flood Disaster Warning System on the go. In: *Proceedings of 2018 7th International Conference on Computer and Communication Engineering (ICCCE), Kuala Lumpur, Malaysia, 19-20 September 2018.* Piscataway, New Jersey: IEEE, pp. 258-263. https://doi.org/10.1109/ICCCE.2018.8539253

[38] BABU, M.V.S.S., JYOTHI PRIYANKA, M., SAI CHERISHMA, J., ADITHYA, G.Y.S. (2017) IoT-based floods alerting system. *SSRG International Journal of Electronics and Communication Engineering*, 4, pp. 41 - 45.

[39] ALFARRA, H. A., and ALSIBAI, M. H. (2017) A wireless smart sensor network for flood management optimization. *International Journal of Engineering Technology and Sciences*, 7(1), pp. 36-42. http://dx.doi.org/10.15282/ijets.7.2017.1.5.1067

[40] HIROI, K. and KAWAGUCHI, N. (2016) FloodEye: Real-time flash flood prediction system for urban complex water flow. In: *Proceedings of 2016 IEEE SENSORS Conference, Orlando, Florida, USA, 30 October - 3 November 2016.* Piscataway, New Jersey: IEEE, pp. 1-3. http://dx.doi.org/10.1109/ICSENS.2016.7808626

[41] PAN, J., YIN, Y., XIONG J., LUO, W., GUI, G., and SARI, H. (2018) Deep learning-based unmanned surveillance systems for observing water levels. *IEEE Access*, 6, pp. 73561 - 73571. http://dx.doi.org/10.1109/ACCESS.2018.2883702

[42] SHEIKH AZID, B. S., RAGHUWAIYA, K., CHAND, A., PRASAD, S., JACQUIER, A. (2015) SMS-based flood level monitoring system. *ARPN Journal of Engineering and Applied Sciences* 10(15), pp. 6387 - 6391. Available from: https://www.researchgate.net/publication/283101853_SMS_based_flood_monitoring_and_early_warning_system

[43] VANAMA, V. S. K., BABU, K. V. S., and RAO, Y. S. (2020) Ground truth mapping with multi-temporal earth observation data in ESA CloudTool box: A case of Kerala flood event occurred in 2018. In: *Proceedings of 2020 International Conference on Emerging Smart Computing and Informatics (ESCI), Pune, India, 12-14 March 2020*. Piscataway, New Jersey: IEEE, pp. 133-136. https://doi.org/10.1109/ESCI48226.2020.9167570

[44] KWAK, Y., PELICH, R., PARK, J., and TAKEUCHI, W. (2018) Improved flood mapping based on the fusion of multiple satellite data sources and in-situ data. In: *Proceedings of IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia, Spain, 22-27 July 2018*. Piscataway, New Jersey: IEEE, pp. 3521-3523. https://doi.org/10.1109/IGARSS.2018.8517336

[45] GOFFI, A., STROPPIANA, D., BRIVIO, P. A., BORDOGNA G., and BOSCHETTI, M. (2020) Towards an automated approach to map flooded areas Sentinel-2 MSI data and soft integration of water spectral features. *International Journal of Applied Earth Observation and Geoinformation*, 84, Article ID 101951. https://doi.org/10.1016/j.jag.2019.101951

[46] ZHAO, X., LIANG, D., and MARTINELLI M. (2017) MPM simulations of dam-break floods. *Journal of Hydrodynamics*, 29(3), pp. 397-404. https://doi.org/10.1016/S1001-6058(16)60749-7

[47] CHOKMANI, K. *et al.* (2019) The use of remotely sensed information within a flood risk management and analysis tool (GARI). In: *Proceedings of IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, Yokohama, Japan, 28 July-2 August 2019.* Piscataway, New Jersey: IEEE, pp. 4636-4639. https://doi.org/10.1109/IGARSS.2019.8898218

[48] ZHAO, J. and YU, X.-D. (2018) Cross validations of radio-frequency interference signature in AMSR-E data using two detection methods. *Atmospheric and Oceanic Science Letters*, 11(3), pp. 255-261. https://doi.org/10.1080/16742834.2018.1440133

[49] ZHENG, W. (2019) Algorithm of flood monitoring and analysis based on SMAP data. In: *Proceedings of 2019 IEEE 8th Joint International Information Technology and Artificial Intelligence Conference (ITAIC), Chongqing, China, 24-26 May 2019.* pp. 911-914. https://doi.org/10.1109/ITAIC.2019.8785459

参考文:

[1] HASHIM, Y., IDZHA, A. H. M. 和 JABBAR, W. A. (2018) 無線洪水監測系統的設計和實現。電信、電子和計算機工程雜誌 (JTEC)，10(3-2)，第 7-11 頁。可從 https://www.researchgate.net/publication/329389934_The_Design_and_Implementation_of_a_Wireless_Flood_Monitoring_System

[2] AHMED, N., GHOSH, S., HASSAN, R. A., GALIB, S. I., AZAD, A. K. 和 SYRUS, M. A. (2017) 處理山洪暴發的梯度傳感中間件。計算機與電氣工程，62，第 44-52 頁， https://doi.org/10.1016/j.compeleceng.2017.08.006

[3] NOYMANEE, J., NIKITIN, N. O. 和 KALYUZHNAYA, A. V. (2017) 在北大年盆地使用開放數據和機器學習技術進行城市洪澇預測。继续計算機科學，119，第 288-297 頁 https://doi.org/10.1016/j.procs.2017.11.187

[4] NARATHIP, S. 和 CLAUDIO, S. (2019)。通過巨災建模了解馬來西亞的洪水風險。可從：https://www.brinknews.com/19987

[5] LOMBARDI, A.、COLAIUDA, V.、VERDECCHIA, M. 和 TOMASSETTI, B. (2021) 以用戶為導向的預警系統水文指數，使用事後調查進行驗證：亞平寧中部地區的洪水案例研究.水文學和地球系統科學，25(4), 第 1969-1992 頁。 https://doi.org/10.5194/hess-25-1969-2021

[6] NORASHIKIN, S.、RABIEAHTUL A.B. 和 TANOT, U. (2018) 吉隆坡的山洪影響——方法審查和前進方向。國際馬來世界與文明雜誌，6(1)，第 69-76 頁。 https://doi.org/10.17576/jatma-2018-06SI1-10

[7] HONG J. L. 和 HONG, K. A. (2016) 使用人工神經網絡預測吉隆坡巴生河的洪水。國際混合信息技術雜誌，9(3)，第 39-60 頁。 https://doi.org/10.14257/ijhit.2016.9.3.05

[8] WONG-PARODI, G.，FISCHHOFF, B. 和 STRAUSS, B. 韌性與適應：框架和行動。氣候風險管理，10(C)。 https://doi.org/10.1016/j.crm.2015.07.002

[9] SULAIMAN, S. (2019) 馬來西亞是否位於太平洋火環中？法律視角。在：冰雪奇缘 2018 - 法律、環境和社會法律與自然國際會議，雪蘭莪州萬宜

馬來西亞，2018 年 11 月 13-16 日。班吉：馬來西亞克邦桑大學，法學院，第 181-190 頁。https://doi.org/10.15405/epsbs.2019.10.20
[10] SCHANZE, J. (2018) 洪水風險管理：一個不斷發展的特定領域。洪水風險管理雜誌，11(3)，第 227-229 頁。https://doi.org/10.1111/jfr3.12487
[11] JABBAR, W. A. (2020) 质量保证-OLSRv2 和医学硕士-OLSRv2 路由協議基於移動性的性能比較。在：2019 年第 23 屆國際計算機科學與工程會議 (国际证券交易委员会) 的論文集，泰國普吉島，2019 年 10 月 30 日至 11 月 1 日。新澤西州皮斯卡塔韋：IEEE，第 281-286 頁：https://doi org/10.1109/ICSEC47112.2019.8974771
[12] JABBAR, W. A.、ISMAIL, M.、NORDIN, R. 和 RAMLI, R. M. (2017) EMA-MPR：多路徑 OLSRv2 的能量和移動感知多點中繼選擇機制。在：2017 年 IEEE 第 13 屆馬來西亞國際通信會議 (MICC) 會議錄，2017 年 11 月 28 日至 30 日，馬來西亞柔佛州新山。新澤西州皮斯卡塔韋：IEEE，第 1-6 頁。https://doi.org/10.1109/MICC.2017.8311721
[13] JABBAR, W. A., RAMLI, R. M. 和 ISMAIL M. (2020) 移动网络中质量保证-OLSRv2 和医学硕士-OLSRv2 路由協議的比較性能分析。在：2020 年網絡、計算機和通信國際研討會 (ISNCC) 的會議記錄，加拿大蒙特利爾，2020 年 10 月 20-22 日。新澤西州皮斯卡塔韋：IEEE，第 1-6 頁 https://doi.org/10.1109/ISNCC49221.2020.9297241
[14] JABBAR, W. A., SAAD, W. K., HASHIM, Y., ZAHARUDIN, N. B. 和 ABIDIN, M. F. B. Z. (2018) 基於阿杜诺的光伏太陽能係統升降壓轉換器。在：2018 年 IEEE 學生研究與發展會議 (得分) 會議記錄，馬來西亞雪蘭莪州班吉，2018 年 11 月 26-28 日。新澤西州皮斯卡塔韋：IEEE，第 1-6 頁。https://doi.org/10.1109/SCORED.2018.8710807
[15] JABBAR, W. A., WEI, C. W., AZMI, N. A. A. M. 和 HAIRONNAZLI, N. A. (2021) 基於物聯網树莓派的智能校園停車管理系統。物聯網，14(4)，第 100387. https://doi.org/10.1016/j.iot.2021.100387
[16] JABBAR, W. A., YUZAIDI, M. A. B., YAN, K. Q., BUSTAMAN, U.S., HASHIM, B. M. Y. 和 ALARIQI, H. T. (2019) 基於阿杜诺和射频無線模塊的智能綠色路燈系統。在：2019 年第 8 屆建模仿真和應用優化國際會議 (ICMSAO) 的論文集，巴林麥納麥，2019 年 4 月 13-15 日。新澤西州皮斯卡塔韋：IEEE，第 1-6 頁。https://doi.org/10.1109/ICMSAO.2019.8880451
[17] SAAD, W. K., HASHIM, Y. 和 JABBAR, W. A. (2020) 便攜式智能無線人行橫道控制系統的設計與實現。IEEE 訪問，8，第 106109-106120 頁。https://doi.org/10.1109/ACCESS.2020.3000014
[18] RAHMAN, M. R. 和 THAKUR, P. K. (2018) 使用合成孔徑雷達 (特区) 衛星數據和地理信息系统檢測、測繪和分析洪水傳播：印度奧里薩邦肯德拉帕拉區的案例研究。埃及遙感與空間科學雜誌，21，第 S37-S41 頁. https://doi.org/10.1016/j.ejrs.2017.10.002
[19] CHI, S., WEI, C., ZHENG, J., HU, J., LI, M. 和 HU, J. (2018) 中國水閘調控河流

大型無脊椎動物群落分佈格局及其關係與河流縱向連通。總體環境科學，631-632，第 765-777 頁。https://doi.org/10.1016/j.scitotenv.2018.02.132

[20] DHARSHANA, D.、WICKRAMASINGHE, M. 和 SAMARAWICKRAMA, J. (2017) 明渠鹽度和防洪閘門自動控制系統。在：第 28 屆運輸現像國際研討會論文集 [ISTP28]，斯里蘭卡佩拉德尼亞，2017 年 9 月 22-24 日。佩拉德尼亞：佩拉德尼亞大學。可從：https://www.researchgate.net/publication/320880849_An_automatic_control_system_for_sluice_gate_in_salinity_and_flood_control_in_open_canal 獲得。

[21] UEYAMA, J., FAIÇAL, B.S., MANO, L.Y., BAYER, G., PESSIN, G. 和 GOMES, P.H. (2017) 增強自適應河流監測系統無線傳感器網絡的可靠性：對其長期的思考 在巴西部署。 計算機、環境和城市系統，65，第 41-52 頁。https://doi.org/10.1016/j.compenvurbsys.2017.05.001

[22] UDO, E. 和 ISONG, E. (2014) 使用無線傳感器網絡的洪水監測和檢測系統。亞洲計算機與信息系統雜誌，1(4)，第 2321-5658 頁。

[23] GUILLÉN-NAVARRO, M. Á.、PEREÑÍGUEZ-GARCÍA, F. 和 MARTÍNEZ-ESPAÑA, R. (2017) 基於物聯網的作物霜凍預測系統。在：2017 年智能環境 (IE) 國際會議論文集，第 28-35 頁。https://doi.org/10.1109/IE.2017.38

[24] GUIBENE, W., NOWACK, J., CHALIKIAS, N., FITZGIBBON, K., KELLY, M. 和 PRENDERGAST, D. (2017) 智能城市低功耗广域网技術評估：河流監測用例。在：2017 年 IEEE 無線通信和網絡會議研討會 (WCNCW) 的論文集，美國加利福尼亞州舊金山，2017 年 3 月 19-22 日。新澤西州皮斯卡塔韋：IEEE，第 1-5 頁。https://doi.org/10.1109/WCNCW.2017.7919089

[25] SAGAR, S. V., KUMAR, G. R., XAVIER, L. X., SIVAKUMAR, S., 和 DURAI, R. B. (2017) 西法特：採用防洪技術的智能灌溉系統。在：2017 年第三屆科學技術工程與管理國際會議 (图标) 的論文集，印度欽奈，2017 年 3 月 23-24 日。新澤西州皮斯卡塔韋：IEEE，第 28-33 頁。https://doi.org/10.1109/ICONSTEM.2017.8261252

[26] MAHMOOD, A., JABBAR, W. A., SAAD, W. K., HASHIM, Y. 和 MANAP, H. B. (2018) 砷化镓-鳍式场效应晶体管晶體管的最佳納米尺寸通道。在：2018 年 IEEE 學生研究與發展會議 (得分) 會議記錄，馬來西亞雪蘭莪，2018 年 11 月 26-28 日。新澤西州皮斯卡塔韋：IEEE，第 1-5 頁。https://doi.org/10.1109/SCORED.2018.8710811

[27] MAHMOOD, A., JABBAR, W. A., HASHIM, Y. 和 MANAP, H. B. (2019) 縮小溝道尺寸對砷化镓-鳍式场效应晶体管晶體管電氣特性的影響。國際電氣與計算機工程雜誌，9(4)，第 2902-2909 頁。https://doi.org/10.11591/ijece.v9i4.pp2902-2909

[28] ATALLA, Y.、HASHIM, Y. A.、GHAFAR, N. A. 和 JABAR, W. A. (2019) 基於溝道氧化物厚度的 (硅鳍式场效应晶体管) 溫度特性。電信，17(5)，第 2475-2480 頁。

https://doi.org/10.12928/TELKOMNIKA.v17i5.11798

[29] AL ARIQI, H. T., JABBAR, W. A., HASHIM, Y. 和 MANAP, H. B. (2019) 矽納米線晶體管的表徵。電信，17(6)，第 2860-2866 頁。 https://doi.org/10.12928/TELKOMNIKA.v17i6.13084

[30] MARZUKHI, S.、SIDIK, M.、NASIR, H.、ZAINOL, Z. 和 ISMAIL, M. N. (2018) 洪水檢測和預警系統 (流量)。在：第 12 屆普適信息管理和通信國際會議 (国际通信组织'18) 會議記錄，馬來西亞蘭卡威，2018 年 1 月 5-7 日。紐約：計算機協會，第 1-4 頁。 https://doi.org/10.1145/3164541.3164623

[31] ATIJOSAN, A., SALAU, A. O. BADRU, R. A. 和 ALAGA, T. (2017) 基於社區的低成本實時洪水監測和預警系統的開發。國際科學、工程和技術科學研究雜誌，3(3)，第 189-195 頁。可從：https://ijsrset.com/IJSRSET173344

[32] AHMED, N., AZAD, AK, KHAN, MR, HABIB, A., GHOSH, S., 和 SHAHID, S., (2016) 绍纳邦杜：一個基於雲的系統來處理山洪暴發在： 2016 年網絡系統和安全國際會議 (系统管理系统) 會議記錄，孟加拉國達卡，2016 年 1 月 7-9 日。新澤西州皮斯卡塔韋：IEEE，第 1-6 頁。

[33] SOUZA, S.A., DE LIMA CURVELLO, A.M., DOS SANTOS DE SOUZA, F.L., 和 DA SILVA, H.J. (2017) 對關鍵區域的洪水預警系統，继续計算機科學, 109, 第 1104-1109 页. https://doi.org/10.1016/j.procs.2017.05.453

[34] MOUSA, M., ZHANG, X. 和 CLAUDEL, C. (2016) 使用超聲波和紅外傳感器在城市中檢測山洪。IEEE 傳感器雜誌，16(19)，第 7204-7216 頁。 https://doi.org/10.1109/JSEN.2016.2592359

[35] PALLAVI, C. V. (2017) 基於雲的无线传感器网络和物聯網洪水監測系統開發。國際工程與技術研究雜誌 (射流)，4(5)，第 2937-2943 頁。可從：https://www.academia.edu/33567166/Development_of_Flood_Monitoring_System_using_WSN_and_IoT_based_on_Cloud

[36] RASHID, B. 和 REHMANI, M. H., (2016) 無線傳感器網絡在城市地區的應用：調查。網絡和計算機應用雜誌，60，第 192-219 頁。 https://doi.org/10.1016/j.jnca.2015.09.008

[37] ABDULLAHI, S. I., HABAEBI, M. H. 和 MALIK, N. A. (2018) 洪水災害預警系統。在：2018 年第 7 屆計算機與通信工程國際會議 (国际商会) 會議記錄，馬來西亞吉隆坡，2018 年 9 月 19-20 日。新澤西州皮斯卡塔韋：IEEE，第 258-263 頁。 https://doi.org/10.1109/ICCCE.2018.8539253

[38] BABU, M.V.S.S., JYOTHI PRIYANKA, M., SAI CHERISHMA, J., ADITHYA, G.Y.S. (2017) 基於物聯網的洪水警報系統。SSRG 國際電子與通信工程雜誌，4，第 41 - 45 頁。

[39] ALFARRA, H. A. 和 ALSIBAI, M. H. (2017) 用於洪水管理優化的無線智能傳感器網絡。國際工程技術與科學雜誌，7(1), 第 36-42 頁。 http://dx.doi.org/10.15282/ijets.7.2017.1.5.1067

[40] HIROI, K. 和 KAWAGUCHI, N. (2016) 泛濫之眼：城市復雜水流的實時山洪預測系統。在：2016 年 IEEE 傳感器會議論文集，美國佛羅里達州奧蘭多，2016 年 10 月 30 日至 11 月 3 日。新澤西州皮

斯卡塔章：IEEE，第 1-3 頁。http://dx.doi.org/10.1109/ICSENS.2016.7808626

[41] PAN, J., YIN, Y., XIONG J., LUO, W., GUI, G., 和 SARI, H. (2018) 基於深度學習的無人水位監測系統。IEEE 訪問，6，第 73561 - 73571 頁。http://dx.doi.org/10.1109/ACCESS.2018.2883702

[42] SHEIKH AZID, B. S., RAGHUWAIYA, K., CHAND, A., PRASAD, S., JACQUIER, A. (2015) 基於短信的洪水位監測系統。ARPN 工程與應用科學雜誌 10(15), 第 6387 - 6391 頁。可從：https://www.researchgate.net/publication/283101853_SMS_based_flood_monitoring_and_early_warning_system

[43] VANAMA、V.S.K.、BABU、K.V.S., 和 RAO、Y.S. (2020) 欧空局云工具箱中多時相地球觀測數據的地面實況映射：2018 年發生喀拉拉邦洪水事件。在：2020 年國際會議論文集新興智能計算和信息學 (欧洲证券投资委员会)，印度浦那，2020 年 3 月 12-14 日。新澤西州皮斯卡塔章：IEEE，第 133-136 頁。https://doi.org/10.1109/ESCI48226.2020.9167570

[44] KWAK, Y.、PELICH, R., PARK, J. 和 TAKEUCHI, W. (2018) 基於多個衛星數據源和現場數據的融合改進洪水測繪。在：IGARSS 2018 - 2018 年 IEEE 國際地球科學和遙感研討會論文集，西班牙巴倫西亞，2018 年 7 月 22-27 日。新澤西州皮斯卡塔章：IEEE，第 3521-3523 頁。https://doi.org/10.1109/IGARSS.2018.8517336

[45] GOFFI, A., STROPPIANA, D., BRIVIO, P.A., BORDOGNA G., 和 BOSCHETTI, M. (2020) 迈向从哨兵-2 微星绘制淹没区域的自动方法數據和水光譜特徵的軟整合.國際應用地球觀測和地理信息雜誌，84，文章 ID 101951。https://doi.org/10.1016/j.jag.2019.101951

[46] ZHAO, X., LIANG, D., 和 MARTINELLI M. (2017) 潰壩洪水的 MPM 模擬。流體動力學雜誌，29(3)，第 397-404 頁。https://doi.org/10.1016/S1001-6058(16)60749-7

[47] CHOKMANI, K. 等。 (2019) 在洪水風險管理和分析工具 (加里) 中使用遙感信息。在：IGARSS 2019 - 2019 年 IEEE 國際地球科學和遙感研討會論文集，日本橫濱，2019 年 7 月 28 日至 8 月 2 日。新澤西州皮斯卡塔章：IEEE，第 4636-4639 頁. https://doi.org/10.1109/IGARSS.2019.8898218

[48] ZHAO, J. 和 YU, X.-D. (2018) 使用兩種檢測方法對 AMSR-乙數據中的射頻干擾特徵進行交叉驗證。大氣和海洋科學快報，11(3)，第 255-261 頁。https://doi.org/10.1080/16742834.2018.1440133

[49] ZHENG, W. (2019) 基於 SMAP 數據的洪水監測分析算法。在：2019 年 IEEE 第八屆國際信息技術和人工智能聯合會議 (国际贸易协会) 的論文集，中國重慶，2019 年 5 月 24-26 日。第 911-914 頁。https://doi.org/10.1109/ITAIC.2019.8785459