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IMU (inertial measurement unit) device for internet of things based disaster early warning system: applications and innovation

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Abstract. The various natural disasters which happen in this world push us to develop an integrated and thorough natural disaster prevention system. In an era full of technologies, accessing data become much easier that it has become probable to decrease the loss caused by natural disaster. The internet of things has powerful role in increasing the prevention of natural disaster. Also, the application of inertial measurement unit has been promoted as universal component that can serve as a tool to monitor the parameters of a natural disaster. This is some examples of several applications of IMU device in general uses and in disaster related uses. This paper serve as a way to develop new ideas about IoT based IMU device, which can be a pillar in developing a disaster responsive society.

1. Background and motivation

Various natural disasters that occur can include monetary loss, and even several human lives. Even natural disasters can cause mental disorders due to the traumatic events that it caused.

History noted several massive natural disasters in the world that caused unbelievable damage, such as Mount Tamboras eruption (1815), Vietnam typhoon (1881), Mount Krakatoas eruption (1883), Haiyuan earthquake (1920), tsunami in Indonesia and India (2004), Haiti earthquake (2010), and several others [1] [2].

The lack of information access for the people becomes one of the factors of several losses caused by natural disasters. People tend to use natural signs as a parameter for an upcoming natural disaster, which accuracy cannot be guaranteed.

In this modern age, there have been many development of sophisticated technology. This development can be used to increase mitigation measures on natural disasters. One of the uses of the technology for natural disaster mitigation is internet of things (IoT) based technology using IMU (inertial measurement unit) device. This device can estimate orientation change of an object and also tracking it. This device consists of accelerometer, gyroscope, and magnetometer, where each of them can operate on three perpendicular axes.

2. Inertial measurement unit

IMU (inertial measurement unit) is an electronic device that can measure the acceleration of an object, angular movement and magnetic field measurement on an area. This electronic device is a combination of accelerometer, gyroscope, and magnetometer sensors. These three sensors measure in the three components direction which is a perpendicular to one other. IMU is applied on airplane maneuver, and also unmanned vehicle such as spaceship and satellite launch. Several IMU device is also used on navigation system that replaces GPS when there is no GPS signal available in place like tunnels, buildings, and because of other signal interference.

Generally, IMU is a MEMS (micro electro mechanical system) that uses micro electric fabrication technique. This technique creates a mechanic structure of a microscopic scale that uses silicon as raw material. MEMS sensor can be used to measure physical parameter to 0 Hz frequency (static measurement).

Accelerometer is used to measure the acceleration of an object. The principle of the system is to detect the position change of a mass because of effect from a movement, either a tilt change or collision. Gyroscope is a sensor to measure and maintain the position with a principle of angle momentum. Gyroscope mechanically shaped like a disc that has a free oriented axis. Magnetometer is a sensor that is used to measure magnetic field in a point.

3. IMU device available as a main component of IoT based mitigation system

Inertial measurement unit device can be used as main component in IoT based disaster mitigation system using dynamic motion principle. Comparison on available IMU models on the market is displayed on table 1. Every module is made from several sensor integrated to one other to increase the feature from IoT system that will be built. A good IMU module is a module that uses a low current and voltage consumption but has high performance.

4. IMU applications in general

In general, the inertial measurement unit can be used for various needs in various fields.

4.1. Detection of obstruction and movement of pedestrian

IMU device can be combined with ultrasonic sensor to map obstruction such as cliff or wall in a path that will be passed by pedestrian. IMU device will give information on position during the trip and the ultrasonic sensor will give information on obstruction. Ultrasonic sensor will be put on waist and detect objects in front of it. One of the outputs of the mapping can be used as reference for hikers to gain information on certain hiking trails [3]. Figure 1 showing an overview of algorithms to detection of obstruction and movement of pedestrian.

4.2. Robot movement detection

Position and movement lane of robot can be known with the IMU device. IMU can also be used to control and operate the robot wirelessly [4].

4.3. Arm movement detection

IMU device innovation has so many uses in the process of making animation movies, one of which is the movement of human arm that can be detected using combination of several IMU devices. Three IMU device are put on palm, lower arm, and upper arm of the person. The data then will be sent to an interface device on real-time [5].

Table 1. Comparison on available IMU models on the market.

Module	**Measurement Range (±)**	

	Power Consumption (all mode)	Accelerometer (g)	Gyroscope (dps)	Magnetometer (Tesla)	**Supply Voltage**	**Operating Temperature Range (°C)**	**Output Data Rate**
SparkFun 6 Deg of Freedom Breakout - LSM6DS3	6 µA - 1.25 mA	2 - 16	125 - 2000	-	1.71 - 3.6 V	-40 - +85	up to 1.6 kHz
Kootek GY - 521MPU60X0	10 µA - 3.9 mA	2 - 16	250 - 2000	-	2.75 - 3.46 V	-40 - +85	Accelerometer: up to 1 kHz Gyroscope: up to 8 kHz
SparkFun IMU Fusion Board ADXL345 IMU3000	Accelerometer: 0.1 µA - 145 µa Gyroscope: 5 µA - 6.1 mA	2 - 16 2 - 16	250 - 2000	-	Accelerometer: 2 - 3.6 V Gyroscope: 2.1 - 3.6 V	-40 - +85	Accelerometer: up to 3.2 kHz Gyroscope: up to 8 kHz
SparkFun 6 Deg of Freedom IMU Digital Combo Board - ITG3200/ADXL345	Accelerometer: 0.1 µA - 145 µA Gyroscope: 5 µA - 6.5 mA	2 - 16 2 - 16	2000	-	Accelerometer: 2 - 3.6 V Gyroscope: 2.1 - 3.6 V	-40 - +85	Accelerometer: up to 3.2 kHz Gyroscope: up to 8 kHz
Sunkee 10Dof 9 - axis Altitude Indicator	Accelerometer: 0.1 µA - 145 µA Gyroscope: 5 µA - 6.1 mA Magnetometer: 2 µA - 100 µA	2 - 16 2 - 16 2 - 16	250 - 2000	8 x 10^-4	Accelerometer: 2 - 3.6 V Gyroscope: 2.4 - 3.6 V Magnetometer: 2.16 - 3.6 V	-40 - +85 -30 - +85	Accelerometer: up to 3.2 kHz Gyroscope: up to 800 Hz Magnetometer: up to 600 Hz
Adafruit 9Dof IMU Breakout - L3GD20 + LSM303	Accelerometer: 1 µA - 110 µA Gyroscope: 5 µA - 6.5 mA Magnetometer: 2 µA - 100 µA	2 - 16 2 - 16 2 - 16	250 - 2000	1.3 x 10^-4 - 8.1 x 10^-4	Accelerometer: 2.16 - 3.6 V Gyroscope: 2.4 - 3.6 V Magnetometer: 2.16 - 3.6 V	-40 - +85	Accelerometer: up to 220 Hz Gyroscope: up to 760 Hz Magnetometer: up to 220 Hz
10 Dof MEMS IMU Sensor	Accelerometer: 0.1 µA - 145 µA	2 - 16	2000	8 x 10^-4	Accelerometer: 2 - 3.6 V	-40 - +85	Accelerometer: up to 3.2 kHz

	Gyroscope: 5 µA - 6.5 mA	2 - 16			Gyroscope: 2.1 - 3.6 V		Gyroscope: up to 8 kHz
	Magnetometer: 2 µA - 100 µA	2 - 16			Magnetometer: 2.16 - 3.6 V	-30 - +85	Magnetometer: up to 160 Hz
SparkFun 9Dof Razor IMU M0 MPU9250	8 µA - 3.7 mA	2 - 16	250 - 2000	4.8 x 10^-3	2.4 - 3.6 V	-40 - +85	Accelerometer: up to 4 kHz Gyroscope: up to 8 kHz Magnetometer: up to 200 Hz
DIY Drones ArdulMU + V3 SparkFun MPU6000 NMC5883L	Accelerometer: 10 µA - 3.9 mA	2 - 16			Accelerometer: 2.37 - 3.46 V	-40 - +85	Accelerometer: up to 1 kHz
	Gyroscope: 10 µA - 3.9 mA	2 - 16	250 - 2000	8 x 10^-4	Gyroscope: 2.37 - 3.46 V		Gyroscope: up to 8 kHz
	Magnetometer: 2 µA - 100 µA	2 - 16			Magnetometer: 2.16 - 3.6 V	-30 - +85	Magnetometer: up to 160 Hz

4.4. Sea wave level measurement
Buoys that is used as a wave measures on a beach has big sizes and also high costs on installation and maintenance. IMU device become a solution because of it's smaller and efficient size. IMU can map water level on a beach by using an interface device [6].

4.5. Magnetic field anomaly detection
IMU consists of accelerometer, gyroscope, and magnetometer, where each of them can operate on three perpendicular axes which can be used to map magnetic field anomaly in a certain area. By knowing the position parameters that can be obtained from IMU principle, the area which has the biggest domination of magnetic field anomaly can be known. The mapping can be done by walking or by unmanned vehicle [7].

4.6. Stone movement detection on curling
IMU application can be used on sports, such as curling. IMU device is placed on thrown stones by the athlete to know the movement of the stone. The score displayed on a certain interface device can be used by the athlete as an evaluation on training [8].

4.7. Detecting symptoms of decreased body function
In medical field, IMU can be used to identify leg paralysis from a persons walking style. IMU is placed on instep, calf, and thigh. Symptoms of paralysis can be seen on a persons walking style that is not normal anymore, such as leg that swings to outer region and unstable [9].

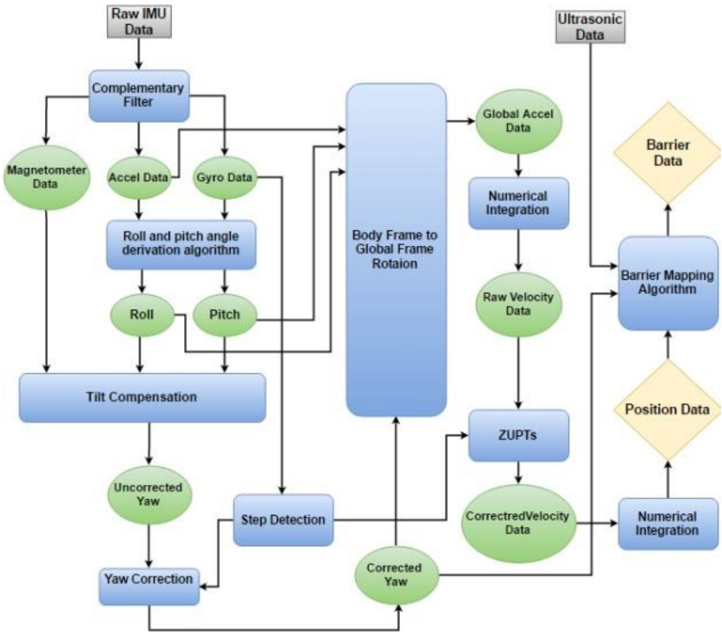

Figure 1. Flowchart showing an overview of algorithms to detection of obstruction and movement of pedestrian [3].

4.8. Ideal oar usage for rowing athletes
Other innovations for IMU device is development on ideal oar for rowing athletes. By knowing rowing techniques and comfortable movements that rowing athletes used, oar with ideal angles and more playability for athletes can be developed. This development is a combination between the coach, biomechanics and the rowing equipment [10].

5. IMU applications on disaster
In particular the inertial measurement unit can be used as an early warning system in mitigating natural disasters.

5.1. Earthquake
Earthquake is a form of sudden energy release that causes a vibration on Earth's surface, caused by propagation of seismic wave. The strength of a quake can start from a small scale that can be felt, to a very large scale that can cause so much destruction. The effects of an earthquake not also including building damage, but also primary effects such as subsidence and surface faulting, also secondary effects such as displaced rocks, tsunami, fracture, liquefaction, and landslide [11]. According to a research from Japan, easy access of data for people is very important as early warning system to reduce traffic collisions when earthquake occurs. Japan Meteorology Agency (JMA) introduced a new term, earthquake early warning, for toll road users. When information about earthquake is being transmitted by radio transmissions, drivers were expected to not panic by reducing their vehicles speed or even stop on the road side. This method can reduce traffic collision compared to when drivers kept driving in high speed when earthquake occurs [12].

In this scenario, IMU device can be collaborated with IoT system to identify the occurrence of earthquake, and then the data can be transmitted to the user. Earthquake activities cause movements on Earth's surface as a parameter that can be measured using IMU.

Characteristics of an earthquake can also be analyzed using quake catcher network (QCN) by connecting the accelerometer system to the internet. The sensors which use MEMS (Micro Electro Mechanical System) principle and applied to 180 unit in Christchurch area to record aftershocks after the Darfield earthquake in New Zealand on 2010. Sensor will be monitored real-time by host computer,

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and then the report will be sent to central server. Epicenter and the quakes intensity will be predicted quickly based on parameter of ground movement which has been received by the IMU device [13].

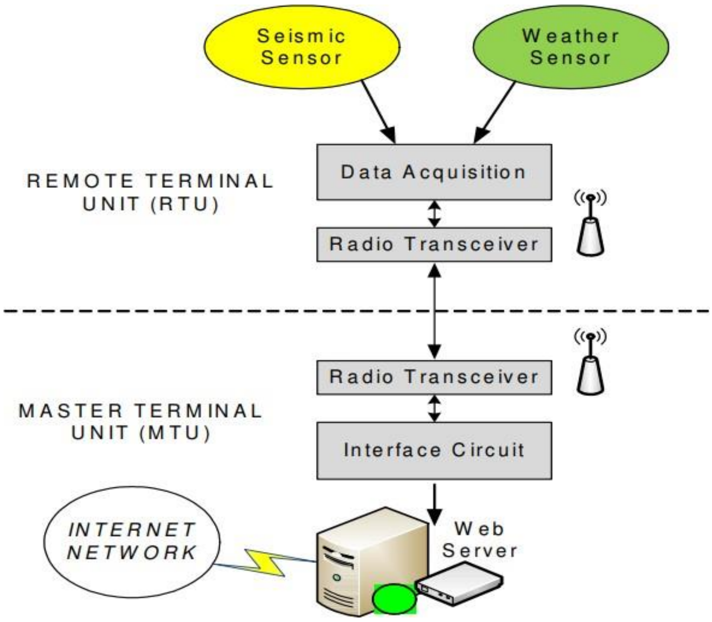

Figure 2. Block diagram of the instrumentation system to measuring the seismicity parameter of volcanic eruption [14].

5.2. Volcano eruption

Volcanic eruption is an event where magma came out from inside the earth because of accumulation of huge pressure inside of the volcano. Volcanoes are commonly found at plate subduction zones. Effects from volcanic eruptions are volcanic ash, lahar, mud flow, forest fire, toxic gas, volcanic quake and even tsunami. Volcanic eruption can be analyzed as consideration on natural disaster mitigation. Several studies about volcanoes are often done by scientists from time to time. Parameters used as reference for the status of a volcano are also being updated. Several parameters that are still being used on monitoring a volcanos status are the seismicity level and volcano deformation because of volume gain. These two parameters can be measured by using IMU device integrated with real-time operating IoT system, so that the data can be easier to access by user as study on volcanic eruption mitigation.

One of the IMU devices that have been developed is a MEMS based accelerometer as a main component in measuring the seismicity parameter of volcanic eruption, with affordable price. This sensor is a 3 axis sensor with g-select feature which let the user to select the sensitivity level. In its application as seismic sensor, on a static mode the sensor will give an output to 0 volt as to not using high electricity power. When the sensor detects any quake, the output value will displayed according to selected sensitivity level [14]. Figure 2 showing a block diagram of the instrumentation system to measuring the seismicity parameter of volcanic eruption.

Next is volcano deformation which is connected to volume gain of the volcano. The parameter that can be measured is the change of the slopes skewness from a point outside the volcanos system. Helens volcanic eruption on 1980 pushed scientists, especially geophysicists, to predict a future event and to determine a volcanos physical condition. The research done at Helens volcano includes automatic skewness measurement on predicting eruption. Tiltmeter is designed to be integrated with USGS system and the data can be transmitted telemetrically [15].

5.3. Lahar

Usually, lahar is caused by heavy rain on mountain summit. Materials around the summit can be transported by the rain and have a potential to brought pebbles to boulders to mountain foot. Of course, this will be dangerous for the people on the mountain foot, especially on a downstream area which is passed by the lahar. To execute the mitigation or reducing the disasters risk, an instrument that can detect a lahar potential must be developed to evade material and even live loss.

One of the features from the Inertial Measurement Unit is a measurement by tracking. Sensors will be integrated with IoT based system so that accessing the data for analysis is easier. Overall, the system is composed of node and gateway. The node will be placed on several spots along the river which have the potential to have lahar, in which many people has reside especially on the downstream. Each node has IMU sensor and added microcontroller plus several other components, such as LoRa transmitter which function as data transfer to gateway system. Nodes are also equipped with solar panels, lipo battery and charger module as voltage supply regulator.

The gateway functions as a bridge between data obtained by nodes and central server. The gateway system is also placed on several spots along the river. The gateway can be made using Raspberry Pi3B+ module as controller unit and LoRa Gateway as data receiver from each node. On the gateway, solar panels, voltage regulator and accumulator as voltage supply regulator are also used.

The data read on the node will be transmitted to the server by gateway in certain time intervals. When the value from each node changes significantly following certain patterns, it can be assumed that the area is being caught on a lahar. Before that, the obtained data must be analyzed first to determine the speed of the tracking node to consider the threat level which has the potential to damage. The system design is shown in Figure 1 and Figure 2.

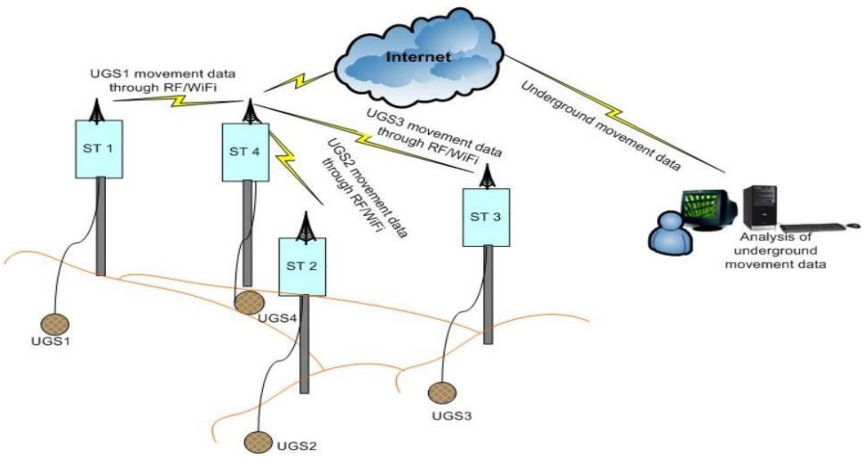

Figure 3. Landslide detection sensor network [17].

5.4. Landslide

Landslide is a movement of landmass in the form of the movement of materials from a land slope. A landslide can occur because of the grounds weight gain caused by rain. Rain water which is absorbed by the grounds pores will accumulate above a slip plane, causing landslide. Various studies have been done to reduce the damage caused by landslide, in this case, remote sensing technology have a big role in hazard analysis in recent years [16].

IMU device combined with IoT technology made it possible to serve easily accessed data for people who live around steep slopes. IMU can be used to monitor movement of ground mass caused by external causes such as rain and mass gain above the slope, which can be a cause for landslide. Parameter measurable by using IMU is the change of slopes skewness. One of the outputs of the sensor is a velocity value which can be conversed to angle change to show skewness change of the slope. Besides that, the sensor model can be projected on an interface device to make it easier for the user in analysis process.

IMU device has been developed to detect landslide threat on real-time intended for detecting long movement and speed of ground movement. Parameter gained from the sensor is the sensors velocity data and relative angle movement using concept from Inertial Measurement Unit [17].

5.5. Tsunami

Tsunami is a big wave caused by a disturbance on the bottom of the ocean such as sea quake caused by tectonic plate shift. Tsunami can also occurs caused by sudden mass gain such as falling of a huge rock. These disturbances caused waves that spread to all directions with gaining amplitude when nearing land but decreasing in speed.

Mitigation for tsunami usually done by using buoys placed on the coast, but measurement like this still has its limitations. Commonly, measurement of tidal wave on the coast is done by measuring the sea level relatively to a certain reference while the altimetry measurement is not done continually and precisely. Besides, usage of conventional buoys also has bigger weight and expensive.

IMU device can be used as tsunami early detection sensor because of its smaller size and relatively cheaper installation and maintenance cost. One of the researches done on Anping Port, Taiwan, shows that the lower-cost IMU has good ability to measure wave height with amplitude and frequency as quite accurate parameter [18].

6. IMU movement tracking for disasters detection: an innovation

As described in section 4, the use of the IMU to monitor movement has been successfully carried out on general subject. They use algorithms to combine three sensors on the IMU to be able to know the position and orientation periodically. This principle is used to track movement. But the IMU application on early detection of disasters as listed in section 4 still uses one of the IMU sensors. Therefore the use of IMU for disaster detection is not optimal. The purpose of this review article is to initiate innovation using the movement tracker on the IMU to be pinned on the nodes installed for early detection of disasters.

Almost all natural disasters can be detected by monitoring the movements of objects in the disaster. IMU sensors installed on these objects can be an early detection tool. Tsunami begin with changes in sea level. This sea level change can be monitored using the IMU sensor. The sea level change data can be sent to the server to be considered as a tsunami early warning. Landslides can be detected by the same principle by installing an IMU sensor on a vulnerable cliff. When a landslide occurs, the sponsor will record the movement of the cliff. In areas prone to volcanic disasters, IMU sensors can be installed to monitor lahar.

7. Conclusion

Internet of Things became a solution in easier data access for people. Easier data access by the people can increase mitigation attempt against natural disasters. Disaster mitigation can be well executed if combined with efficient electronic devices that can operate optimally in recording data in real-time. There is much development in Inertial Measurement Unit based sensors as a disaster mitigation device to minimize damage and victim because of natural disasters. This review aims to compare and solve many problems regarding disasters that can be solved using IoT based IMU device.

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