Development of the Cloud-Based Magnetic Data Acquisition System for Real Time Geomagnetic Monitoring

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Abstract. Magnetic Data Acquisition System (MAGDAS) is a system of a real-time magnetometer data logger deployed by Kyushu Sangyo University of Fukuoka, Japan as part of Japan’s leading contribution to International Heliophysical year of the United Nations. This paper proposed a cloud-based MAGDAS for the YU-8T magnetometer. MAGDAS is the system that measures and monitors the earth’s magnetic field or geomagnetic field. Converting the old system to the new system will provide the capability to monitor the magnetic field changes continuously due to the solar activities which are harmful to the electrical appliances. To verify the workability of the system, the data from the MAGDAS Langkawi and solar event was gathered to be compared with the developed system. The location where the measurement takes place is at Pusat Sukan UiTM Shah Alam, Selangor, Malaysia (geographic latitude and longitude: 3.00N, 101.00E, and geomagnetic latitude and longitude: 6.37S, 173.65E. This project consists of the YU-8T magnetometer system, hardware, software, and cloud-based web-server. YU-8T magnetometer measures the voltage of Earth’s magnetic field in the form of H, D and Z parameters to be stored in the data logger. The stored data was transferred to the cloud-based web-server through the Internet of Thing (IoT) for real-time monitoring.

1. Introduction
Real-time Magnetic Data Acquisition System (MAGDAS) of Circum-pan Pacific Magnetometer Network (CPMN), for space weather study and application, was installed for the International Heliophysical Year (IHY; 2007-2009) by the International Center for Space Weather Science and Education, ICSWSE, Kyushu University, Japan [1][2]. The MAGDAS project has the purpose of monitoring the Earth’s magnetic field. Different from space-based observation, this ground-based network contributes the space observation. Data from both ground and space observation are necessary to adequately study solar-terrestrial activity. MAGDAS is the largest magnetometer network in the world. MAGDAS can create geomagnetic measurements in real-time. In Malaysia, the first magnetometer station was installed at Langkawi National Observational (LNO), Langkawi [3]. The real-time magnetometer data logger deployed by Kyushu Sangyo University is possible to be used for hardware deployment, due to the hardware and data logger issue which require follow up maintenance throughout time and high cost of the existing data logger technology. The author decided to develop a low cost and reliable IoT magnetic data acquisition system which able to replace the existing technology of the real-time magnetometer data logger. Data acquisition system (DAQ) is a computerized system to measure physical occurrence such as voltage, current, temperature, pressure, or sound by the use of sensors [5]. The system converts analog values into digital values to facilitate data processing. Figure 1 shows the MAGDAS/CPMN (Magnetic Data Acquisition System/Circum-pan Pacific Magnetometer Network) system.
The system consists of three main parts which are YU-8T geomagnetic sensors, measurement hardware or analog to digital converter module, and programmable software with a computer. Data Acquisition System builds up the network hardware platform which can be used to monitor real-time data [6]. The Magnetometer is a device that measures magnetism either the polarization of magnetic material or the direction, strength of a magnetic field at the specific area. Earth's magnetic field or geomagnetic field is a vector quantity; whereas it has the strength and a direction. YU-8T is a 3-component fluxgate magnetometer that measures the Earth’s magnetic field by measuring its HDZ component. Fluxgate magnetometers are used to measure small magnetic fields using the magnetization of a soft ferromagnetic core [7][8]. Fluxgate of the magnetometer which has the advantages of small dimension, vector measurement, and robustness, are widely used to detect weak static magnetic field at room temperature and found applicability in many filed such as submarine detection, space, and aerospace magnetic survey, geomagnetic field mapping and others [9]. YU-8T magnetometer consists of a 3-component magnetic field sensor and its analog amplifier. The value of WMM coefficients needs to be updated every five years because of the unpredictable non-linear changes in the core field [10]. Figure 2, 3 and 4 show the geomagnetic range of Malaysia referred to WMM.
Based on Figure 2 to 4, the horizontal intensity of the magnetic field in Malaysia is 40000nT and above. Declination intensity is 0nT and field down intensity in the range of 0 to -10000nT. Table I summarize the magnetic field range based on WMM and Pusat Sukan UiTM Shah Alam and in Malaysia.

**Table 1. Geomagnetic Range Reading at Pusat Sukan UiTM Shah Alam**

| Parameter   | Geomagnetic range in Malaysia (WMM) | Geomagnetic range at Pusat Sukan UiTM Shah Alam (WMM) |
|-------------|--------------------------------------|-------------------------------------------------------|
| H component | 40000nT to 43000nT                   | 41318.6nT                                             |
| D component | 0 nT                                 | 0nT                                                   |
| Z component | -15000 nT to 20000 nT               | -7144.6nT                                             |
2. Methodology
The YU-8T is a Japanese three component fluxgate magnetometer with core rings in operation. The sensitivity of the magnetometer is approximately 0.1 nanoTesla (nT). The YU-8T is used to measure the voltage of the Earth’s magnetic field. The YU-8T connects with the amplifier, SN60 by using a cable. The SN60 then connects to the filter box that goes to the input of the ADC circuit module. (H + δH, D + δD, Z + δZ) of the geomagnetic data equipped with a 10Hz sample rate. The surrounding magnetic field, H (horizontal intensity), D (magnetic declination) and Z (vertical component) are digitized by using the ADC module. The magnetic variations (δH, δD, δZ) data are additionally digitized by the A/D at pre-amp by 24 bits and 10Hz resolution and sampling frequency separately. Geomagnetic field variation in 1 sec per 24 hours can be recorded using the YU-8T fluxgate magnetometer. The sensitivity of the output connector of the YU-8T magnetometer is +-300nT/+-10V.

2.1. Overview of YU-8T MAGDAS system
The surrounding magnetic field, H (horizontal intensity), D (magnetic declination) and Z (vertical component) are digitized by using the ADC module. The magnetic variations (δH, δD, δZ) data are additionally digitized by the A/D at pre-amp by 24 bits and 10Hz resolution and sampling frequency separately. Geomagnetic field variation in 1 sec per 24 hours can be recorded using the YU-8T fluxgate magnetometer. The sensitivity of the output connector of the YU-8T magnetometer is +-300nT/+-10V.

2.2. Block Diagram of the DAQ system
Figure 5 shows the block diagram of the Magnetic Data Acquisition System of the YU-8T MAGDAS system. The system starts logging the data as soon as the command given to the Raspberry Pi. Analog input which is H, D and Z component from the YU-8T magnetometer is sent to the pre-amplifier to amplify the signal. A filter box is used to reduce the analog voltage which comes from the sensor. The filtered analog voltage is then converted to a digital voltage by the Analog-Digital Converter circuit module. The IP address needs to be similar for the hardware and cloud server for data transfer. The Cloud system involves the interconnection of embedded system type devices to a given cloud platform service(s), with communication completed through specific network protocols and interconnections [11]. The data were log using Node-Red storage node in CSV file. The memory card of 8GB is already sufficient for data storage for more than 6 months. In the migration case, the application will be redeployed to a different hardware environment with a new application infrastructure configuration with minimal effort [12]. The data store for 1 month takes about 500MB from the SD card which still has a lot of space left for a year of usage. However, the data from H, D, and Z files were taken once every 3 months to prevent the SD card from using excessive space. The file will be automatically uploaded to the cloud and stored on a magnetic monitoring website.

![Figure 5. Block diagram of Data Acquisition System (DAQ) system.](image)
2.3. YU-8T Magnetometer installation guidelines
YU-8T magnetometer installation guideline is important for a good installation process. Each installation step from the magnetometer manual needs to be followed for better data acquisition and a better installation process. The YU-8T Magnetometer is an electrical device used to measure the geomagnetic field. First, to collect H-component data, X and Y-axis component arrow from the magnetometer needs to be aligned with the true North with the help of a compass. After the component has been aligned with the true North, calibrate the pre-amplifier to get D component and Z component. To get an accurate result, the magnetometer needs to be installed far from any electrical disruptions and other magnetic disturbances. Moreover, human activities, cars, and roads also can lead to interruption to the measured result. Figure 6 shows the optimum distance needed for YU-8T Magnetometer testing. The optimum distance from any other electrical disturbance should be around 30 meter.

![Figure 6](image)

**Figure 6.** The best distance for testing the YU-8T magnetometer.

2.4. Hardware Development
Figure 7 shows the schematic diagram for the Analog to Digital converter module. The schematic diagram for the hardware has been designed by using PROTEUS software. Each component of the circuit is assembled and soldered according to the schematic diagram. The circuit diagram consists of two-part which are a digital part and an analog part. The digital part consists of the ESP32 ADC module and raspberry pi 3 which is working as a data controller. The analog part consists of ATMEGA 328P and voltage divider circuit which is used to lower down the input voltage from the pre-amplifier through the BNC connector. BNC connector is where the H, D and Z analog voltage were collected. ATMEGA 328P is moving at the frequency of 16MHz by following the Crystal frequency place in the circuit. Each component of the circuit is assembled and soldered properly according to the schematic diagram.

![Figure 7](image)

**Figure 7.** The Schematic Circuit on PROTUES Software
The circuit connection has been constructed properly so that any wrong connection or unconnected component can be prevented. From the develop data logger. The Final hardware prototype is powered by 2 power supply which is 12V barrier jack for the circuit board and 5V 2.5A power supply for the raspberry pi which is connected to 5 inch LCD. Figure 8 shows the data logger circuit on board.

![Figure 8. The data logger circuit on board](image)

2.5. YU-8T setup with DAQ system

Figure 9. Shows the setup for the Data Acquisition system with the YU-8T magnetometer. The YU-8T is connected to the pre-amplifier. The amplifier amplifies and displays the input data of the sensor. The pre-amplifier is then connected to the filter box to filter the amount of voltage goes to the circuit. The output of the circuit goes to the ESP32 before transferring the data to Raspberry pi 3. Raspberry pi 3 working as the data collector before transferring the data to the cloud server.

![Figure 9. YU-8T magnetometer with DAQ installation](image)

The numbering in Figure 9 and 10 is referring to Figure 5 which is the step taken for the data gathering method. YU-8T magnetometer is the magnetic sensor which will detect the H, D and Z component of the magnetic field while pre-amplifier is the device used to display the data of the H, D and Z component from the YU-8T magnetometer sensor. There are few steps needed to adjust the pre-amplifier before collecting the reading of H, D and Z components. The D component of the magnetic field needs to be adjusted closely to zero by moving the magnetometer sensor towards the north-pole. There are marking on the magnetometer sensor which shows X with the arrow direction. The arrow direction of X needs to be adjusted towards the north by using a compass. Once the setup for the D component is completed, the H and Z component can be adjusted by moving the H and Z knob and screw on the pre-amplifier. The H, D and Z component data is transmitted to the FRED SENSETECNIC cloud server. Figure 10 shows the Cloud Server used for data storage and display.
3. Result and Discussion

Based on the magnetic data acquisition system deployment, the data logger can provide real-time data monitoring and the data can be display on the cloud server. The real-time data from the developed magnetic data acquisition system is further discussed in Figure 11 to 13. The discussion is based on real-time data collected from the magnetic data acquisition system deployment.

3.1. Data Collected from 19th to 26th October 2019 from Hardware Deployment

The data gathered from the YU-8T magnetometer data logger and plotted by using MATLAB software. Figure 11 to 13 shows the data taken for H, D and Z components from 19th to 26th October 2019 during hardware deployment at Pusat Sukan UITM Shah Alam.

![Figure 11. H-Component data collection from 19th October to 26th October 2019](image_url)

Based on the H-Component data collected, Figure 11 shows that the data were stable from 19th to 24th afternoon time. However, the data started to fluctuate on both magnetometers starting from 24th October afternoon to 26th October 2019. The data from both Langkawi (LKW) and local data logger having the same pattern. However, the value of the H-component in NanoTesla (nT) is different due to the geographic coordinate that the magnetometer being installed. To identify the accuracy of the...
reading, the plotted data need to be compared with the WMM data. The fluctuation of the H(nT) from 24\textsuperscript{th} October afternoon to 26\textsuperscript{th} October 2019 suspected coming from the solar wind which is moving at a higher speed. The scientific purposes of the MAGDAS system are to study real-time monitoring and modeling of (1) global three-dimensional current systems, (2) plasma mass density and (3) penetration process of polar electric fields into the equatorial ionosphere, to understanding the Sun-Earth coupling system as well as changes to the electromagnetic and plasma environments [3]. For further information, Figure 14 and 15 show the solar wind data which were collected to compare with the data from H Component from the magnetometer.

![Figure 12. D-Component data collection from 19\textsuperscript{th} October to 26\textsuperscript{th} October 2019](image1)

Based on the data collected from D-Component, Figure 12 shows that the D-component data collected from 19\textsuperscript{th} to 24\textsuperscript{th} afternoon time is stable and fluctuated from 24\textsuperscript{th} October afternoon to 26\textsuperscript{th} October 2019. Based on the data collected, it can be concluded that the data from Figure 11 and 12 fluctuated in the same period. It is suspected that the fluctuation causes by the solar wind amendment from the sun. High-speed solar winds produce geomagnetic storms, while slow-speed solar winds produce calm space weather. Therefore, when there is a high-speed solar wind with an open magnetic field (IMF), it is assumed that there will be a solar event at that time [3]. For further discussion on the solar wind amendment, Figure 14 and 15 further discussed on the fluctuation of the solar wind data.

![Figure 13. Z-Component data collection from 19\textsuperscript{th} October to 26\textsuperscript{th} October 2019](image2)
Based on the data from Figure 13, the pattern of the data is similar to Figure 11 and 12. The pattern on the first 5 days is calm and started to fluctuate starting from 24th to 26th October 2019. For further discussion on the range of H, D and Z component data collected in NanoTesla (nT), Table I shows the data gathered for H, D and Z components from 19th to 26th October 2019 at Pusat Sukan UITM Shah Alam.

3.2. The Comparison of Magnetic Field Data with Solar Wind Data

The data from the Magnetic field parameters were compared with the data from the solar wind. Solar events from the sun such as solar wind and solar flare might cause fluctuation of the magnetic field value. The scientific purposes of the MAGDAS system are to study real-time monitoring and modeling of (1) global three-dimensional current systems, (2) plasma mass density and (3) penetration process of polar electric fields into the equatorial ionosphere, to understanding the Sun-Earth coupling system as well as changes to the electromagnetic and plasma environments [3]. Besides investigating the equatorial atmosphere, the behavior of the four components (H, D, Z, and F) can be used to study the significance of having the equator station, where the magnetic field has not been systematically measured before [4].

![Figure 14. Solar wind parameters Interplanetary Magnetic Field,(Bz), Solar Wind Speed and Flow Pressure from 19th October 2019 to 26th October 2019](image)

![Figure 15. Comparison between Symmetric Disturbance Field, SYM/H with Horizontal Intensity, H from Local data logger and Langkawi MAGDAS station](image)
Based on Figure 14 and 15, the parameters for solar wind data plotted are Interplanetary Magnetic Field (Bz), nT (GSM), Solar Wind Speed (km/s), Solar Wind Pressure, nPa and Symmetric Disturbance Field (SYM/H), nT. Based on the comparison, the data of Figure 14 shows that the solar wind parameters dramatically change on the afternoon of 24th October 2019 to 26th September 2019. The value of H, D and Z magnetic field component collected is in the range of H, D and Z magnetic field at the Pusat Sukan UiTM Shah Alam, Selangor Malaysia. Table II shows the magnetic field range from YU-8T Magnetometer, MAGDAS Langkawi and WMM.

### 3.3. Result Benchmarking and Novelty

To ensure the DAQ is working and magnetic data were collected properly, the result obtained from the YU-8T Magnetometer was compared with the worldwide magnetic declination forecast (WMM). The projection of H, D and Z components based on WMM are presented in Figure 2, 3 and 4. The collected result of H, D and Z components from Figure 11 to 13 were compared with the World Magnetic Model 2010 (WMM2015). According to the model guideline, a varying magnetic field in Malaysia for all elements should be positioned such as the Mercator projection. Table II shows the magnetic field range from YU-8T Magnetometer, MAGDAS Langkawi and WMM.

**Table 2. Geomagnetic Range based on YU-8T Magnetometer, MAGDAS Langkawi and WMM**

| Parameter | Geomagnetic range at Pusat Sukan UiTM Shah Alam | Geomagnetic range based on MAGDAS Langkawi | Geomagnetic range at Pusat Sukan UiTM Shah Alam (WMM) |
|-----------|-----------------------------------------------|------------------------------------------|-----------------------------------------------------|
| H component | 41,257.8 nT to 41,420.9 nT | 41,629.93 nT to 41,756.51 nT | 41318.6 nT |
| D component | -23.6499 nT to 18.301 nT | -68.42 nT to -27.86 nT | 0 nT |
| Z component | -7170.91 nT to -7103.12 nT | -1532.12 nT to -1492.84 nT | -7144.6 nT |

Based on the Mercator projection, the Horizontal element, H in Malaysia is approximately 40,000nT and the measured in show the H value is around 40,000nT to 43,000nT and for real environment is in Figure 11 around 41257.8nT to 41420.9nT. For the Declination element, D the measured value needs to be close to 0nT because Malaysia is located near the equator. The value of D in Figure 12 is between -23.6499nT to 18.301nT and the value is approaching 0nT in the afternoon. For vertical component (Z), the magnetometer measured the result in Figure 13 is in the range with the Z component of WMM which is between -15,000nT to 20,000nT. The result collected from Z-component is between -7170.91nT to -7103.12nT. Solar event, magnetic field variation and formation of geomagnetic induced current (GIC) is closely related to each other. The solar event will cause the magnetic field fluctuation and GIC formation in earth ground. Solar flare, coronal holes, coronal mass induction from solar event will cause fluctuation of magnetic field and geomagnetic induce current (GIC)[13]. The fluctuation of the magnetic field and formation of the GIC which is harmful to the electrical appliances. GIC is the ground level manifestation of solar activity which cause harmful effect to the surface technology and buried equipment such as power network, electrical equipment, pipelines, railways and oil gas technology[1]. Therefore, the development of the cloud-based MAGDAS will help to provide the capability to monitor the magnetic field changes continuously due to the solar activities which is harmful to the electrical appliances.
4. Conclusion
The main objective of this research paper is to develop the real-time Magnetic Data Acquisition System for the YU-8T magnetometer to monitor the magnetic field activities. Based on the data collected from the geomagnetic range of YU-8T Magnetometer. The author successfully develops a low cost and reliable IoT magnetic data acquisition system which able to replace the existing technology of the real-time magnetometer data logger. It can be concluded that the geomagnetic range from YU-8T Magnetometer is almost identical to the geomagnetic range from MAGDAS Langkawi and WMM. H, D and Z component of YU-8T Magnetometer is in the range of the geomagnetic field from MAGDAS Langkawi and WMM. Furthermore, the creation of the cloud-based YU-8T magnetometer allows a low-cost reliable data monitoring system from the project conducted.

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