Satellite Tracking Control System for UGM Ground Station based on TLE Calculation

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***Abstract*— UGM ground station requires a satellite tracking control system that can follow the movements of the satellite. The system proposed in this study is relying on the calculation of Two Line Elements (TLE), the reason is that the data TLE has a subtle error. The compass sensor is used to ensure accuracy; the results were evaluated using a protractor, and about 99%. Moreover, this system is also tested to receive images from NOAA satellites using the RTL-SDR and Yagi antennas. In general, this system can follow the motion of the satellite well.**

Keywords—TLE, Tracking Control, NuEdu UNO

I. Introduction

The ground station is one of the essential components in a satellite system [1] [2]. The UGM ground station has a primary focus on the Low Earth Orbit (LEO) satellite, in which UGM is designing the picosatellites as well as using VHF and UHF frequencies. The LEO satellites have short time data acquisition and always on the move during the data acquisition process so the direction antenna system is required so the signal can be received well during this period.

Low Earth Orbit (LEO) extends from an altitude of 200 to 2,000 km. Satellite in this orbit usually has a rotation period of about 90 minutes at a speed of about 7.4 km/sec. Orbit planned for picosatellites UGMSat-1 is LEO. Orbit is also an orbit used by LAPAN A2 which was launched on September 28, 2015.

TLE or Two Line Elements is information that consists of orbital elements. Früh and SCHILDKNECHT state in that error TLE about 2 km or 0.1°.[6] The TLE data at any given period will be updated to ensure accuracy. The TLE data is calculated using software tracking to obtain the azimuth and elevation of the antenna. This study uses the Orbitron (The Satellite Tracking System) Software.

The Example of TLE data for the International Space Station (ISS) is as follows:

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ISS (Zarya)
1 25544U 98067A 12069.11980714 0.00018689 00000-0 24053-3 0 1541
2 25544 51.6413 263.8320 135.4419 323.7930 15.58923824762412 0,017,773
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Software drivers are needed to connect controllers between tracking and control software. In the software tracking Orbitron MyDDE provided additional software to do this, but cannot be directly used. We need to modify myDDE, so the control system of satellite tracking can use it.

The automatic satellite tracking control system was designed based on magnetic rotary encoder also based on TLE calculation from the software, which has accuracy approaching 0.5 – 2 degree.[3] The more complex system was built using H_∞ controller along with the reference signal generated by an improved conventional step-tracking algorithm.[4] This study focuses on a simple design, using TLE calculation result, compass sensor module, and ARM Cortex M0 as a controller (NuEdu UNO from Nuvoton).

II. The Satellite Tracking Control System Design

The satellite tracking control system consisting of two main parts, namely the hardware and software parts, shown in Figure 1.

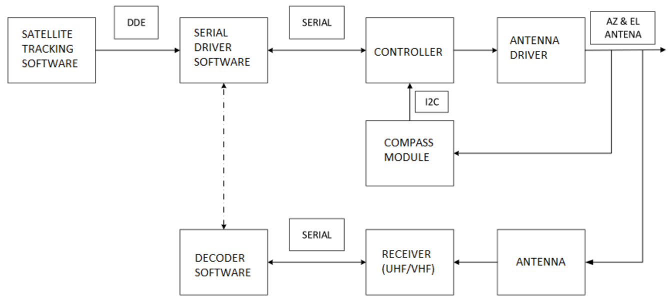

Fig. 1. The Satellite Tacking Control System

A. The Hardware of the system

The hardware system consists of a controller (based on Nuvoton NUC131 ARM Cortex M0), the CMPS11 compass sensor and stepper motor drivers. Figure 2 shows the hardware design of the overall system.

Stepper motor driver circuit serves to help regulate the stepper motor. The controllers do not have enough power to make a stepper motor work, necessitating the stepper motor driver module that meets the required power.

Figure 3 shows the stepper motor driver circuit. The circuit using LM297 as a translator logic to arrange a sequence of pulses given to the stepper motor, as determined by the LM297. The controller no longer needs to perform the function of a sequence of pulses to drive a stepper motor. The other part of the circuit of Figure 3 is the L298 as a current amplifier to drive a stepper motor.

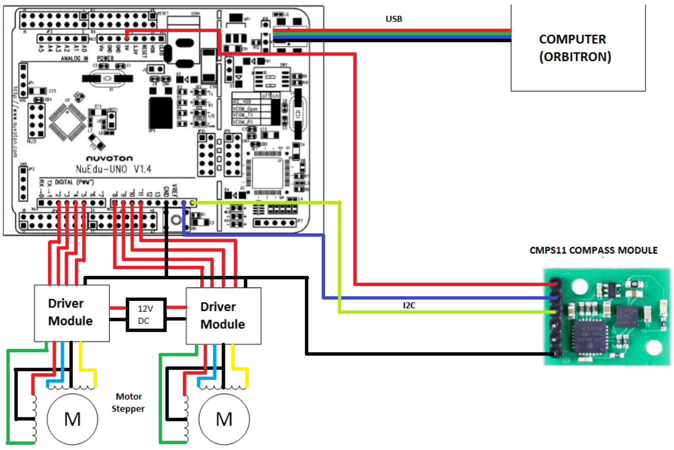

Fig. 2. The Satellite Tacking Control Hardware System

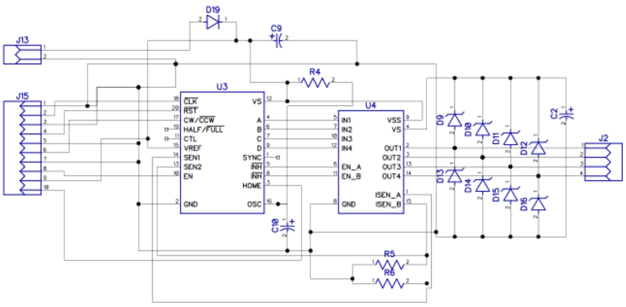

Fig. 3. The Stepper Motor driver circuit

Figure 4 shows the CMPS11 compass sensor module, which serves as a feedback direction of the antenna. This sensor has several features include a compass, gyroscope, and accelerometer. The controller store the results from compass sensor in 27 bytes register and access it via the I^2C interface which is already in the degrees form.

Figure 5 shows the main module of the system that uses NuEdu-UNO based on the Nuvoton ARM Cortex M0 NUC131. This module performs several functions including a stepper motor control, compass sensor data retrieval, send and receive data from the device driver software.

B. The Software of the system

The software used in the satellite tracking control system among other satellite tracking software, software drivers, the control program and the calibration program.

The satellite tracking control system is made using outcomes azimuth and elevation of the satellite tracking software. Figure 6 shows the entries for the location and height of the observer (data from GPS). Figure 7 shows the outputs to be used in the control system.

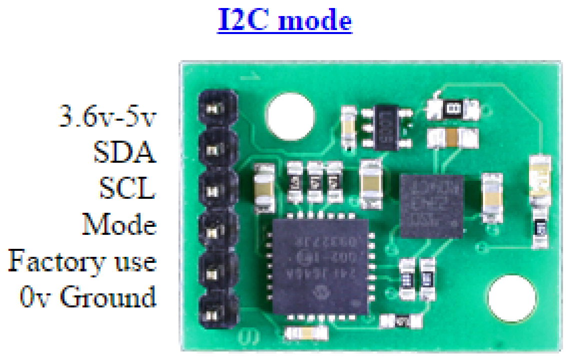

Fig. 4. The Compass Sensor Module (I^2C Mode)

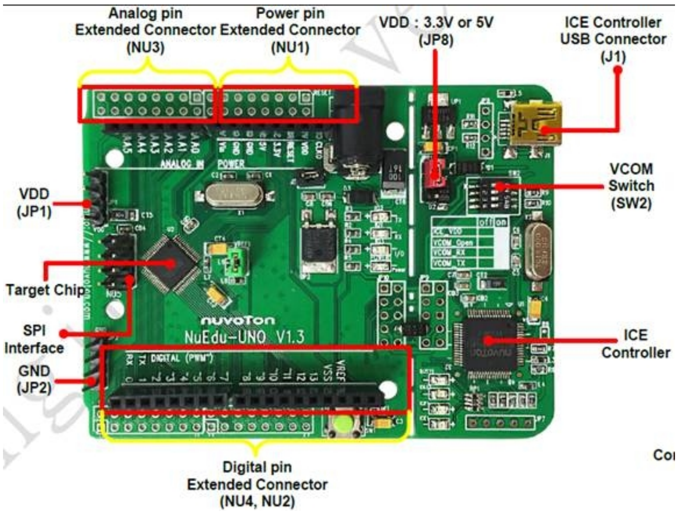

Fig. 5. The NuEdu-UNO module

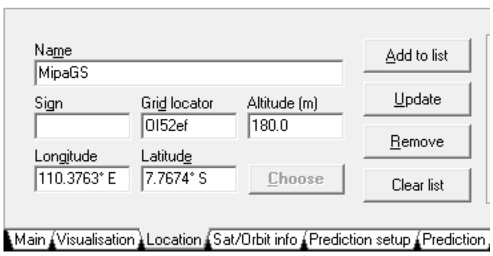

Fig. 6. The Inputs for the software

The azimuth and elevation data in Figure 7 delivered via MyDDE to the controllers. Without the azimuth and elevation data, the control system cannot drive the antenna to the satellite.

Modifications to myDDE done so that the software can transmit data in azimuth and elevation to the controllers via a serial interface. Data obtained through myDDE with a service called "Tracking" is then inserted into the string "SatData" and then split according to the category. The data received are not all used, but only the azimuth and elevation data. Once the data is received, and the format is adjusted, then sent to the controller via serial communications, Figure 8 shows the flowchart.

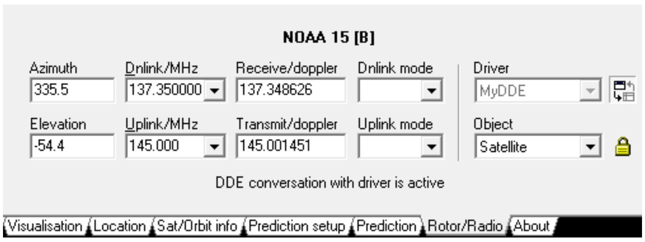

Fig. 7. The Output from the software

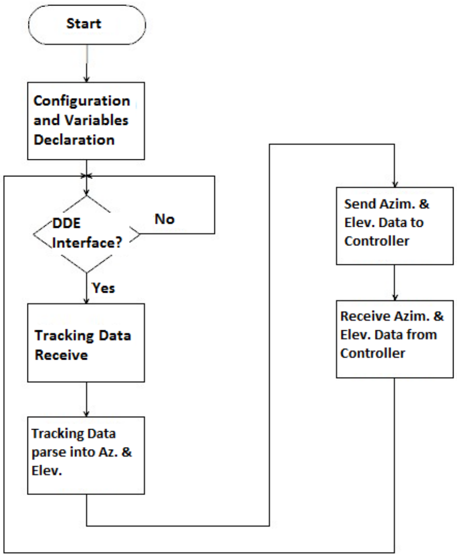

Fig. 8. The Software driver flowchart

Figure 9 shows the control process which begins with serial communication and I^{2}C configuration, define some variables and functions required. Then proceed with reading the azimuth and elevation angles from the CMPS11 compass module. The system obtains the data of antenna angle, then compared with the data submitted by Orbitron via serial communication. If the comparison result is stating that the angle of azimuth and elevation antenna is not the same as the data sent by the Orbitron, the stepper motor is activated to adjust the angle sent by Orbitron.

Compass sensor calibration is required so that the antenna pointed in the right direction at the time of use. Calibration is done by comparing the direction designated by CMPS11 with a protractor. Calibration using the north, the arc angle of zero degrees on axis azimuth (horizontal), as a reference. If there is a difference of more than the value of tolerance, it is necessary to calibrate the sensor CMPS11. The amount of error tolerance can be different depending on the antenna used. Each antenna has a large half-power beam width (HPBW) which vary according to the design. Antennas used in the study was six element yagi antenna with great HPBW ranging from 50° -70°.[6]

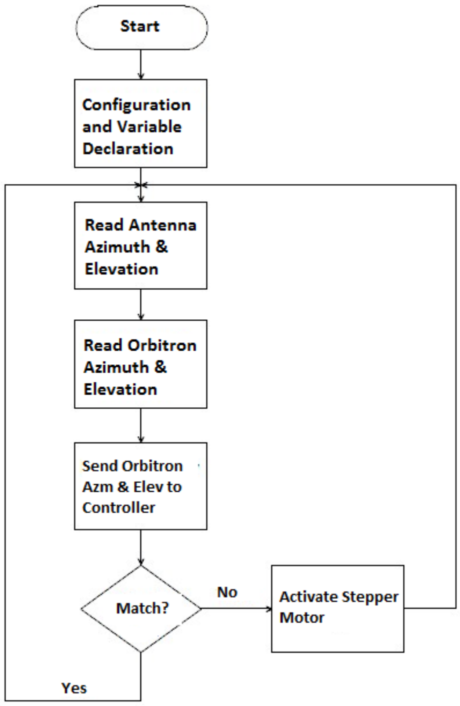

Fig. 9. The Software driver flowchart

The calibration process is done by providing internal calibration code on a compass sensor and compass sensors rotate as far as 360 °. Results angle compass sensor after calibration is evaluated to see if they contain any errors or not. If there is still a relatively large error, the results need to be normalized to the compass sensor calibration calculations. Calibration calculations performed using the following equations [7]

$$S = SK_{max} - SK_{min} \quad (1)$$

$$K = SK - SK_{min} \quad (2)$$

$$N = (K*30) / S + (Region - 1)*30 \quad (3)$$

As far as the azimuth angle of 360° is divided into several areas (regions) per 30°. Start 0°-30° called region 1, 30°-60° called the region 2 and so on up to 12. Angle region on the outcome of the compass sensor is evaluated at the point of the region to get a big error in these points. SK_{max} in equation (1) is the value of the angle sensor results at the upper limit of each region. SK_{min} in equation (1) and (2) are compass sensor angle values result in a lower limit of each region. SK is compass angle sensor results that need to be normalized. Furthermore, the results of equation (1) and (2) is used to get the angle that has been normalized in the equation (3).

III. The Implementation

A. The Motor Stepper Module

Figure 10 shows the assembly results of the stepper motor driver module with the main components, namely L297 (shown in number 1), L298 (shown at number 2). Components with number 3, 4, and five respectively are IDC connectors and connectors for a 5V and 6.3V inputs voltage. Jumper with number 6 is used to set the internal switching chopper L297 and jumpers with the number 7 to set the working mode of the stepper motor. Control input required by a stepper motor through IDC connector, this connector connects to the stepper motor drive and the controller module. Connectors with ABCD pins used to connect the circuit to drive a stepper motor.

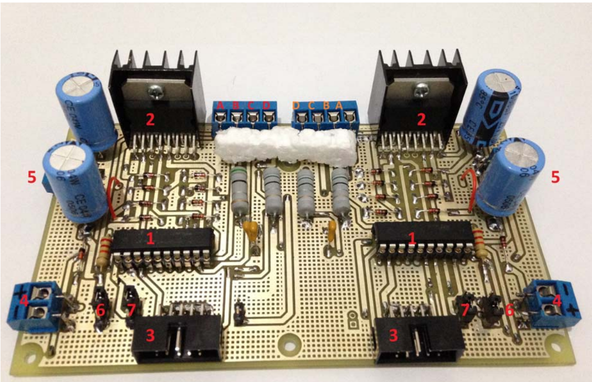

Fig. 10. The Stepper Motor Module

B. The Controller Module and Sensors

The controller (NuEdu UNO) and the compass modules are assembled into one piece using NuEdu Shield; Figure 11 shows the result of combining these modules. The ten pin IDC connector located between the controller module and a compass module used to connect the controller module to module stepper motor drive.

C. The Satellite Tracking Control System

Figure 12 shows the results of the implementation of satellite tracking system control. Just mention before, the system uses six element Yagi antenna.

D. The Calibration Program

Compass sensors are sensitive to the ferromagnetic material, so it is necessary to calibrate the sensor after coupled to a mechanical system. Compass sensor calibration is done by sending a "calibration code" to address 0x60 of the compass sensor (using the I^2C interface). The calibration code that is sent consists of four codes, namely 0xF0, 0xF5, 0xF7 and 0xF8 to quit calibration process.

IV. The Results

Table I shows the results of measuring the azimuth axis, the corrected average range of 1.42 ° or 0.79%, so the accuracy of the axis azimuth angle ranges from 99%. The results obtained through the calibrated compass sensor parameters, and normalization measurements were performed outdoors. Calibration is done significantly affect the outcome antenna alignment because the feedback received from the compass sensor.

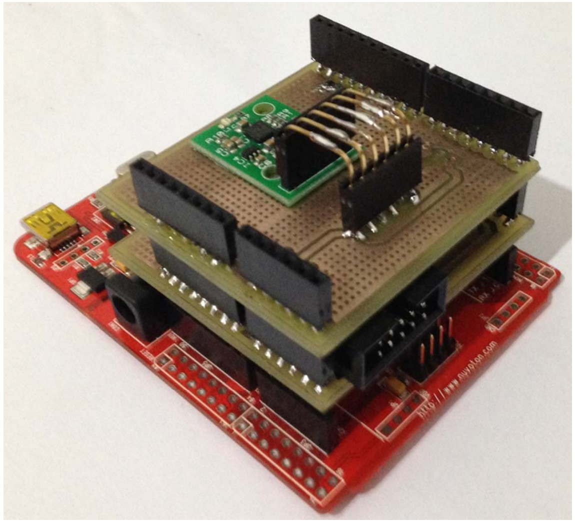

Fig. 11. The Controller Module and the Sensor Module

Fig. 12. The Satellite Tracking Control System

TABLE I. THE AZIMUTH AXIS MEASUREMENT

Angle (°)	**Measurement result (°)**	**Error (°)**
0	0	0
30	29	1
60	59	1
90	89	1
120	118,5	1,5
150	148,5	1,5
180	181	0
210	213	3
240	243	3
270	268	2
300	298	2
330	329	1

Figure 13 shows a graph of Table 1, the compass sensor that is calibrated to both generate corrected average less than 1%. While the average corrected without calibration so great that exceed antenna HPBW. Errata after calibration is an acceptable outcome and results tracking can be said to be true. The average error has generated the criteria beam width antenna ranging from 50 ° -70 ° so that the antenna can receive the signals correctly.

Table II shows the results of testing the angle of elevation; corrected average gained about 0.41 ° or 0.46%, so the accuracy of the elevation angle of about 99%. This accuracy is the best result because the accuracy of the compass sensor is about 1°. These test results elevation angle shows that the system works well and deserves to be used as a satellite tracking control.

Figure 14 shows a graph of Table II; the elevation angle tends to have good results. Unlike the compass sensor that uses the earth's magnetic field to work and accelerometer using gravity to work. Differences in how this causes the difference error at both sensors is very different. The magnetic fields disturbance that affects the compass sensor has no effect on the accelerometer.

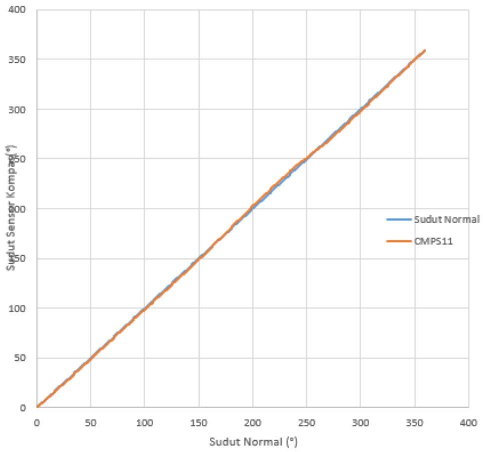

Fig. 13. The Graphic from Azimuth Axis Measurement

TABLE II. THE ELEVATION ANGLE MEASUREMENT

Angle (°)	Measurement result (°)	Error (°)
0	0	0
5	5	0
10	10	0
15	15	0
20	20	0
25	25	0
30	30	0
35	35	0
40	40	0
45	45	0
50	50	0
55	55	0
60	60	0
65	64	1
70	69	1
75	74	1
80	79	1
85	86	1

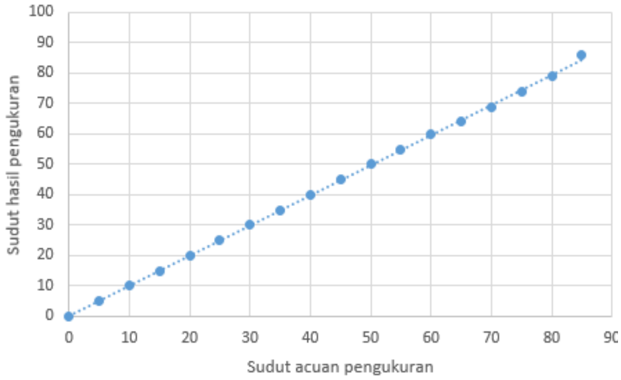

Fig. 14. The Graphic from Elevation Angle Measurement

Elevation determines the signal characteristics shown in Table III. The elevation is the distance between the satellite and the earth station, so the lower the elevation of the smaller received signal strength and the higher the elevation indicates the nearby satellite earth stations and the impact on the signal strength increases. Figure 15 shows the results of satellite imagery from NOAA.

TABLE III. NOAA 15 SATELLITE SIGNAL RECEPTION WITH 93659 ORBIT

Time (AOS)	Elevation	SNR	Fc (Hz)
1	1	0	---
2	5	12	137,623.400
3	10	12	137,623.300
4	14	15	137,623.200
5	20	21	137,623.100
6	26	23	137,622.900
7	31	24	137,622.200
8	32	23	137,621.000
9	30	24	137,620.300
10	23	24	137,619.700
11	17	24	137,619.200
12	12	24	137,618.800
13	7	22	137,618.500
14	3	16	137,618.300
15	1	0	---

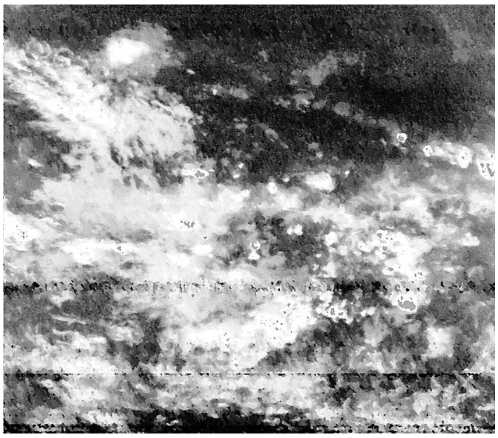

Fig. 15. The satellite imagery from NOAA

ACKNOWLEDGMENT

Thanks to the Indonesian Minister of Higher Education Research and Technology which have provided support and funding to conduct this study. Also thanks to the Satellite and Aerospace Group Research, LPPT UGM for the facilities support.

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