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Building Automatic Antenna Tracking System for Low Earth Orbit(LEO) Satellite Communications

Nimit Hongyim[1]
Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Bangkok 10520, Thailand
nimith@siamsq.net

Somsak Mitatha[2]
Hybrid Computing Research Laboratory, Department of Computer Engineering, Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Bangkok 10520, Thailand

***Abstract*—This paper purposed to implement the Automatic Antenna Tracking system in order to establish the communication with OSCAR (Orbiting Satellite Carry Amateur Radio) for voice (FM, SSB) and data communications (AX.25, packet radio, APRS). There are more than 5 fully operational Amateur satellites both U/V mode and CUBESAT in orbit act as repeaters or Store/ Forward. The often of the activities that came from International Space Station (ISS) sent out picture to ground station with SLOW SCAN TV(SSTV) data protocol. This research areas covered include Azimuth/Elevation Rotor Design and Schematic Controller Interface design.**

Keywords—*Satellite Tracking; AMSAT; OSCAR; Rotor*

I. INTRODUCTION

During cold war era in 1957, Russia (Former USSR) sent Sputnik-1 Satellite [1] which was the 1st beacon Satellite that has external radio antennas to broadcast radio pulses and spending 3 months in orbit then burned up during descending back to Earth on 4 January 1958. The beginning date of the Satellite communication era has begun when the 1st AMSAT (Amateur Radio Satellite) was launched on December 12th, 1961 then many of Amateur radio operators or HAM began to find the way to receive radio signal from OSCAR satellite[2] and the next generation of OSCAR was built and had more features which not limited just send the radio pulse but there are voice mode (FM, SSB) and digital mode with data communications (AX.25, packet radio, APRS, Weather data and Geographic photography). Currently, over 5 fully operational satellites in orbit act as repeaters, linear transponders or store and forward digital relays. as the Low Earth Orbit Amateur Radio station in voice mode and Recently, International Space Station (ISS) started to have communication activities that sent out Picture by using SSTV (Slow Scan TV protocol)[3] over the VHF Radio Frequency to the Ground station around the world over the Low Orbit path that have many countries participated..

In order to establish the communication with LEO Satellite and ISS that will need to have the narrow band direction Antenna point to the correct position over the Sky which will need the Satellite Prediction data such as Azimuth, Elevation and Frequency Doppler Shift. There are the key elements of information that need to have in order to find the position of LEO Satellite and ISS but the chance to make a contact limited period of time and sweep a path across of the observer's sky in a short period of time determined by the orbital parameters of the space craft that chance is very slim. For Example, International Space Station (ISS) path orbit over the sky appear from Horizon to Horizon approximately only 5 minute window which we will need Tracking system with precise position and correct frequency. For the Antenna type, in most case will used Direction antenna in much narrow bandwidth for the quality of signal in case of SSTV or Data communication which will need the stronger signal then Automatic Tracking system become necessary.

In the past, there are 2 main categories of Tracking Systems which are Manual and Automatic Tracking System. The general of Automatic Tracking system or Auto-tracking represented the close-loop tracking system without Radio Operator intervention. The key element of this system is the information that we need to get the AZ/EL and Doppler shift Frequency of each Satellite or Space Craft which will generated by Satellite Tracking software that will calculated and provide these data to interface controller to Drive Rotor for Antenna and also Frequency Doppler shift to Transceiver.

II. DESIGN CONCEPT

In this paper will describe the Auto-Tracking systems which consist of 3 paths: (1) Satellite Tracking Software (2) Rotor Interface (3) AZ/EL Rotor equipped with 2 DC motors.

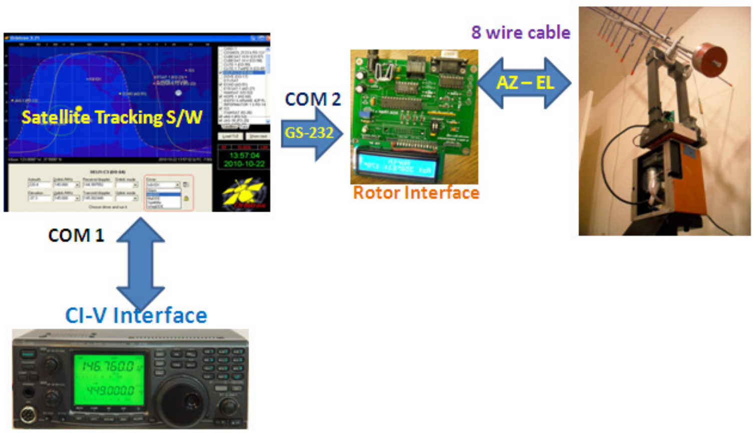

Fig. 1 The Block Diagram of Automatic Tracking system

The over all concept of this scheme can be explained by begin with the Satellite Tracking software which will use TLE. (Two

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lines Element set)[4] TLEs are widely used as input for calculate projecting the future orbital tracks which can be downloaded from NORAD and NASA in order to calculate for AZ/EL then send out via middle ware program to send GS-232 format for Rotor interface board and then send command to control Downlink Frequency data for Transceiver that will perform tuning receiving Frequency which have Doppler shifting effect.

III. AUTOMATIC TRACKING SYSTEM

A. *Satellite Tracking Software (ORBITRON)*

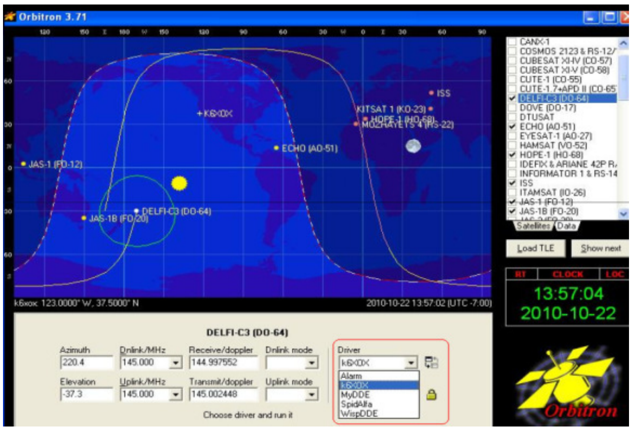

Fig. 2 Orbitron Satellite Tracking Software [5]

There are many of Satellite Tracking software out there in the same category, Some of them Free to use and some of them Paid licensed, We selected this Orbitron Software because of this Software is Free and unlimited license to use. The Tracking software is the key of Satellite Tracking system on both Manual and Automatic system which will provide AZ/EL and Downlink/Uplink Frequency by using TLE which need to get latest updated and download from many of TLE provider site such as NASA and NORAD. Here the sample of TLE for ISS from NASA as Fig 3

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ISS (ZARYA)
1 25544U 98067A   08264.51782528 -.00002182  00000-0 -11606-4 0  2927
2 25544  51.6416 247.4627 0006703 130.5360 325.0288 15.72125391563537
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Fig. 3 An example TLE for the International Space Station [6]

The Orbitron Software made for the general use of Satellite tracking and provides the data but we will need to customized interface act as the middle ware by using DDE (Dynamic Data Exchange) technique. DDE is to allow Windows applications to share data in VB v.6 that used for small interface programmed which will provide output format for Rotor interface board use "GS-232" format [7] as in (1) and Downlink Frequency Doppler shifting to Transceiver.

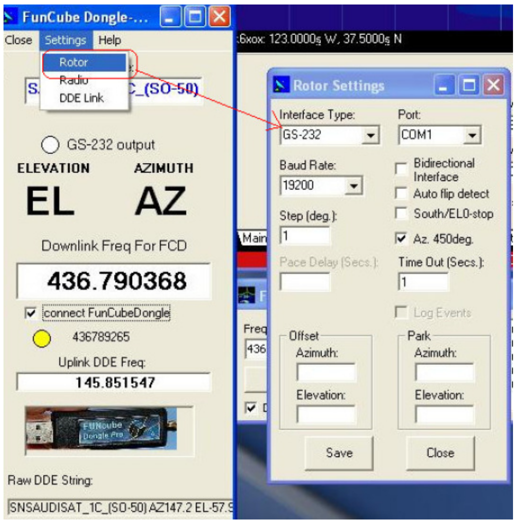

Fig. 4 DDE program interface

GS-232 format: **Wxxx yyy** (1)

Where **xxx** = 000-360 degree of Azimuth

yyy = 000-180 degree of Elevation

Doppler Effect, this is the event that would happen explain while LEO SAT is moving towards to the Ground station, the downlink frequency which might be in UHF or VHF will step changing higher Frequency and when it did orbit pass the Ground station Frequency of Downlink will step changing lower an Transceiver will try to keep up by adjusting accordingly Frequency in order to get the Quality of Signal (QoS). The following mathematical formulas [8][9] which used for calculate the Doppler Frequency change which related the Doppler shift to the velocity of the satellite as in (2)

Change in frequency $\Delta f = f \times \frac{v}{c}$ **Downlink Correction** $f_d = f(1 + \frac{v}{c})$ **Uplink Correction** $f_u = f(1 - \frac{v}{c})$ (2)

Where:

f_d = Doppler corrected downlink frequency for Listing

f_u = Doppler corrected uplink frequency for Transmitting

f = Original frequency which original specification each sat

v = Velocity of the satellite related to ground station in *m/s*. (+) when *moving towards*, (-)when *moving away*.

c = Speed of Light in a vacuum space (3x10^8 m/s).

These calculations are normally done by Satellite tracking software. Transceivers which use for this kind of communication will included a computer interface some of them called CI-V used by ICOM IC-910 Transceiver that used CI-V interface [10] over RS-232 which will communicate with Personal Computer that got data from Orbitron which will provide the correct Uplink/Downlink Frequency number send to Transceiver via CI-V for Automatic Downlink/Uplink Frequency Doppler adjustment for correct frequency.

B. Rotor Interface board

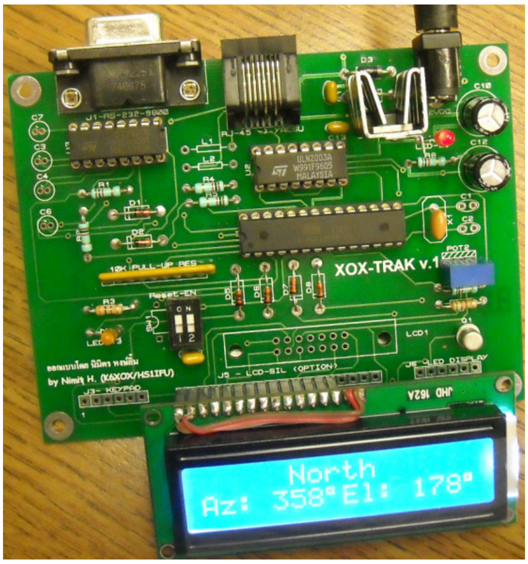

Fig. 5 Rotor Interface Board

This part as shown in Fig 5 is Micro Controller Unit (MCU) that use Atmel ATMEGA328P [11] the firmware development technique using the looping or polling technique from 2 reading Analog input from AS5040 (0v-5v) mapping command with full turn 0-360° = 0v–5V then interrupt command which will receive GS-232 data from Computer RS-232 interface then compare with the current position of both AZ/EL that used Rotary Encoder value provided from Rotor then input to Digital Input pin of MCU in voltage format between 0-5 V use mapping method by software convert to degree of AZ/EL position of Rotor as in Fig 6. MCU programmed to reading , Compare then send output to adjust Up/Down or Turn Left/Turn Right and go back to the begin Loop sequence again as in Fig 7. That explain how the close loop controller will work. at the DC motor controller get the signal from MCU that will send to H-Bridge 2 Ch controller that control AZ/EL motor (up/down and Left/Right). In this design Idea approached to low cost MCU and DC motor controller design technique which result that fast enough to catch up the communication windows start from Satellite appear from horizon to horizon in most case only 5 minute period.

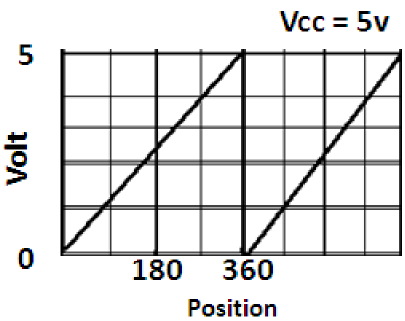

Fig. 6 Analog output from Encoder to A/D of MCU

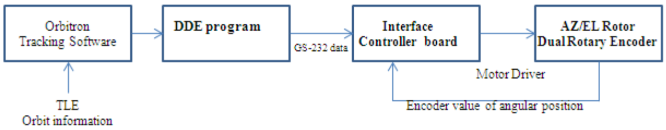

Fig. 7 Block Diagram of Rotor Controller

C. Azimuth and Elevation Antenna Rotor

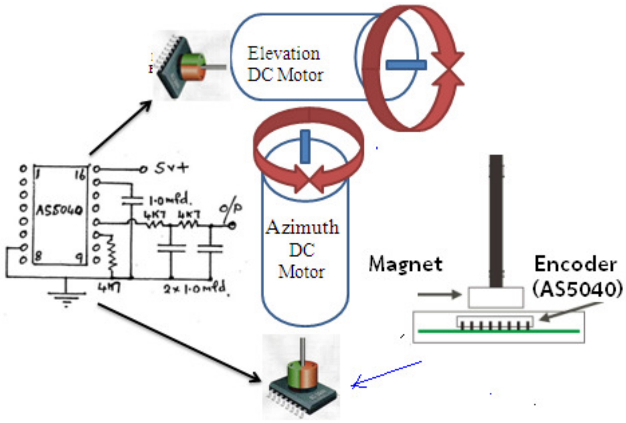

Fig. 8 Magnetic Rotary Encoder

The basic on how to determine the Angular position has been discuss for many solutions and the simplest way is to use POT (Potentiometer) act as voltage divider and feed to A/D of MCU but the POT is only have 270° turn which cannot perform fully turn absolute Revolution of 360° and then this problem has been solved by Magnetic Rotary Encoder because it is no contact from Motor shaft to the sensor so that motor can have full revolution turn without obstruct in sensor mechanical.

The Rotor is designed by using 24 V-DC motor attached with Gear ratio 10:1 at the Gear Drive shaft has 2 Pole magnet over the IC AS5040 [12] from AMS , This IC is a 10-bit rotary position sensor (known as encoder) for Absolute angular measurement and incremental output with full turn of 360° based on Contactless Magnetic Sensor Technology which create a non-contact rotation angle position measurement system. The full Revolution Turn is measured by a resolution of 10 bit equal to 1024 positions per Fully Turn of 360°. This IC AS5040 has many variety of feature for output selection , this designed only used Analog output as 0-5 VDC mapping with 0-360° or per one revolution, by installed these one side 2-pole magnet rotating at the end of the motor Shaft *below or above* this IC AS5040 as in Fig 9

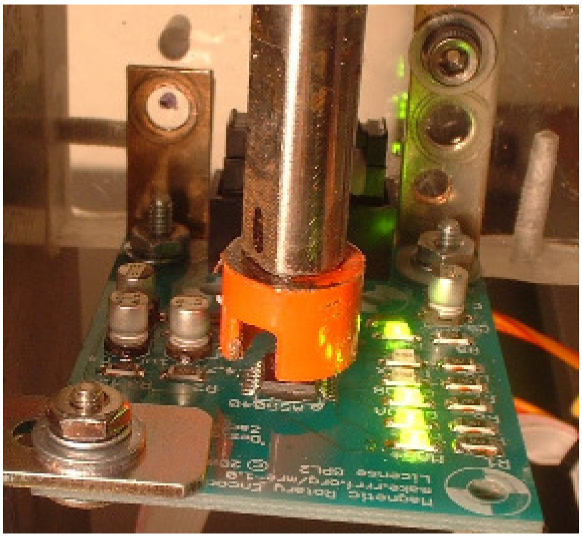

Fig. 9 Actual Magnetic installed above Encoder IC

The H-Bridge DC Motor control of both of Motors with the Rotary Encoder IC can be achieved by using MCU as the feedback the angular position as 0-5 V to the Analog to Digital Pin of MCU which 0-5 V represent the angular position of one revolution for shaft of gear motor. The MCU programmed to perform fine tune (comparing and adjusting) the resolution of the IC in 1024 position in one revolution which accurate enough for tracking Satellite position usually is not exceed +/- 1 or 2 degree. Azimuth Motor is designed to move between 0^o to 360^o and Elevation is designed to move up and down between 0^o to 90^o as in Fig 10

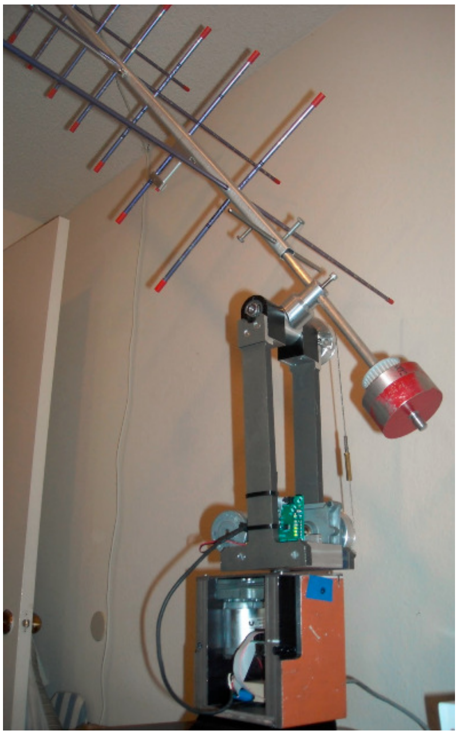

Fig. 10 Antenna installed on Completed Rotor System

IV. Experimental Result

Before to start experiment, there are a few things that need to prepare such as update the TLE data from NORAD or NASA to Orbitron Satellite tracking Software, Checking the output of each Communication port for the Experiment can be separated in 2 parts. 1^{st} part is testing the DDE program output of the Computer to Communication Port in both direction of CI-V interface to Transceiver and verify Frequency readout at the display panel match to the data from DDE and GS-232 to the interface board use the loop back RS-232 to read the result from RS-232 with Terminal program. 1^{st} part experiment shown in fig.10 and the 2^{nd} part is testing for control signal from Interface to driver for DC Motors at the Rotor and then read the result feedback from Rotary encoder back to A/D input to MCU. The calibration of Azimuth is to comparison between AZ/EL actual angular with digital compass for AZ position and use Inclinometer for calibrate EL position and then get the Delta value from calibration use as debugging value for reprogram of Mapping command for MCU for better accuracy.

Field Test was began by setting up the point of reference in the sky if the setup perform in the night time can be used the North Star to setup the 0^o of the AZ and 30^o above the Horizon or if Moon appear over the sky that can be used as the Verify Point of reference. But mostly setup in the day, SUN (use with EYE protection) is the point of reference that we can select from Orbitron software to point and to verify AZ/EL position parameter which provided by Orbitron software to match by Direction Antenna pointing at SUN as reference.

The result of the experiment as expected that selected one of the Telemetry Beacon CUBE Satellite and received the digital signal and also be able to received communication between another ground station to ISS during orbit passed.

The Result of Tracking system, these show the necessary convergence in alignment correction and their dependence on the measurement noise that came from Motor backlash[13] caused from Gear teeth and Gear Ratio which help motor to improved the Accuracy by reduce the backlash (base on quality of Gearbox). Rotary Encoder specification is 1024 position per 360^o which mean *accuracy per one position = 0.35^o* and accuracy that we can get from this simple IC AS5040 Rotary Encoder.

Fig. 11 Testing Satellite Tracking completed Station

TABLE I Summary of Satellite Tracking system

Tracking Category	Remark	Performance	Usage
Manual	Required Operator	Accuracy depend on operator- Generally Low	Most station has manual as backup system
Auto-Track	Close loop auto-tracking	Accuracy approaching 0.5-2° –> if reduce Gear backlash	Shows good overall tracking performance - should be widely used in the future

V. CONCLUSION

Over the past 30 years of space communication, there are many of techniques have been used in Satellite communication tracking system. Shown in Table 1, Both Manual and Auto-tracking can be benefited for those who design the simple Ground station, With technology in this day many of Hi-end component become available for cheap small and powerful MCU, Rotary Encoder and DC motor with Gear Box offered the opportunity to build Automatic Satellite Tracking system, there are many of LEO Satellites. such as GEO-SAT type of this Satellite that keep sending Geographic Picture by SSTV protocol of Earth surface during orbiting and CUBE Satellite[14] that sent by many countries, just for Education purpose which send the Telemetry data for Weather and Geo-Photographic which need to use these Automatic Tracking system can be achieved. With this paper show significant improvement of simple ground station which used to be manual Tracking system.

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