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Research and development of a hexapod tracking controller for VNREDSat-1 satellite

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Abstract:

Current advancements in electronics-telecommunication and mechatronics facilitate development of ground satellite antenna system with more compactness while still ensuring optimal cost and performance. In particular, the antenna pedestal with a six-legged structure (hexapod) based on the Stewart platform is more used thanks to its great performances. The hexapod maneuvers the antenna orientation in elevation and azimuth angles to follow the satellite in orbit. In this paper, the authors present the results in design and developments of a hexapod controller which is the key part of an antenna tracking system. Experiments are performed to track the VNREDSat-1 satellite.

Keywords **—remote sensing satellite, tracking antenna, hexapod.**

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I. INTRODUCTION

Vietnam's first remote sensing satellite VNREDSat-1 (Vietnam Natural Resources, Environment and Disaster Monitoring Small Satellite) was successfully launched into orbit on 7 May 2013. Currently, the VNREDSat-1 satellite is still in stable operation and providing satellite image data for various applications [1].

With the advantages of Earth observation satellites, especially the constellations of Low-Earth orbit observation satellite in terms of applications, research and development of ground control stations is increasingly focused. More specifically, their satellite tracking antenna systems are remarkably compact and high-performance thanks to advancements in mechanics, control and electronics. Hexapod is a dynamic system providing 6 degrees of freedom (6 DOF). With efficient mechanical components, hexapod allows motion generation for up to 1 ton load. Hexapod can also be used to reproduce the trajectories of land, naval or air vehicles and thus facilitate testing of sensors, Satcom antennas, electro-optics systems, etc.

The hexapod structure maneuvers the antenna orientation in elevation and azimuth angles. This mechanism is performed by synchronous motion control of its six linear actuators. This type of structure ownsvarious advantages in terms of accuracy, rigidity and load capacity and is being widely applied in directional control systems including satellite observation tracking antenna. A complete tracking antenna system consists of a hexapod platform and a high-frequency sub-system to track and receive satellite signal[2].

The basic structure of the satellite tracking antenna system using the hexapod structure is shown in figure 1[3].

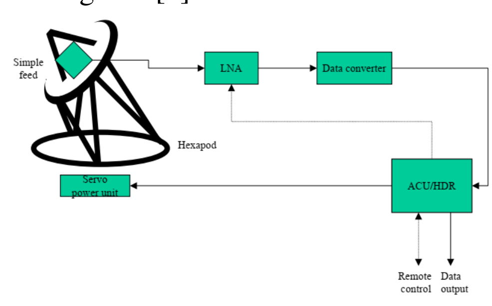

Fig1 A hexapod antenna system

The diagram in Figure 1 depicts an Earth observation satellite receiving system using a hexapod structure to control the direction of the parabolic antenna. In the system, the signal is received from a parabolic antenna and amplified by a low-noise amplifier (LNA), then fed to a frequency converter and a high data rate receiver (HDR). The hexapod structure is controlled by servo motors (Servo power unit) and software on the antenna controller unit (ACU). In order to track the satellite, the controller computes current azimuth and elevation angles of the antenna and the desired positions of six legs accordingly. Consequently, synchronous control of actuators is performed to reach the required pointing of the antenna.

This paper demonstrates the mathematical aspects of the conversion from azimuth and elevation angles to actuators' lengths based on the inverse kinematic problems. Then software design and development of the hexapod controller for tracking the VNREDSat-1 satellite is also demonstrated.

II. HEXAPOD ANTENNA CONTROL SYSTEM FOR VNREDSAT-1

The VNREDSat-1 hexapod satellite tracking antenna system is designed with the structure shown in Figure 2. The system consists of the following parts [4]:

- Antenna: to acquire S-band signal with center frequency of 2240MHz.
- Low Noise Block: to amplify radio signal from antenna and down-convert to intermediate frequency (IF) of 70MHz.
- Hexapod mechanism: to support and point the antenna to track the satellite.

Antenna Control Unit: to perform the key functions such as computation of the antenna direction based on orbital parameters; control the six linear actuators; and other monitoring and alarm tasks.

The designed method for antenna controlling the hexapod base to track the satellite includes two key following steps [4] and [5]:

1. Prediction of the current location of the satellite:

Prediction of the current position of the VNREDSat-1 satellite is done by using the SGP4 (Simplified General Perturbations propagator) model. This model uses the orbital parameters of the satellites which are usually presented as two lines (Two-line Element). The output of this software is the current orientation of the satellite in elevation and azimuth angles. When the satellite enters the antenna ground coverage, the hexapod controller starts manoeuvring the mobile platform by adjusting the positions of the six actuators. The desired lengths are calculated by solving the inverse kinematics problems which is explained in the second step

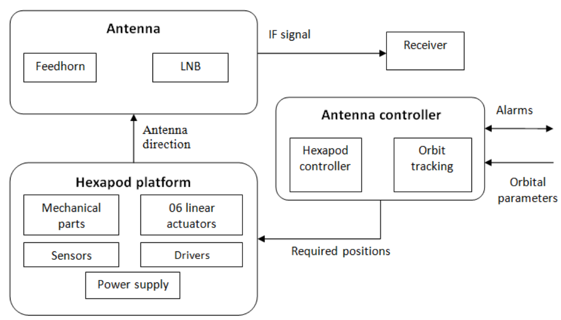

Fig 2 Diagram of the hexapod antenna tracking system for VNREDSat-1 satellite

2. Solving the kinematic problem for the hexapod structure: Calculation of the desired lengths of the 06 axes of the hexapod base by solving inverse kinematics equations. The output of this step is the desired length of the axes. However, this is a very specific step of the hexapod structure control since one orientation of the hexapod base can be achieved by rotating the upper movable plate around the direction axis.

When a hexapod is pointing in a certain direction, this same pointing direction can be maintained by rotating the upper baseplate as shown in Figure 3. Thus, the same pointing direction can be achieved at different heights of the hexapod (by rotating the upper plate around the direction axis). In other words, the problem is solved with various solutions (set of six lengths) to orient the hexapod towards the satellite.

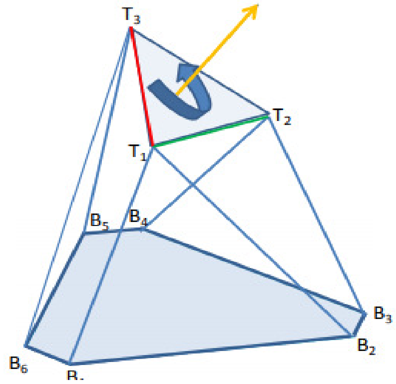

Fig 3Pointing direction of the hexapod mobile platform

The purpose of inverse kinematic is transformation from azimuth and elevation angles to six leg lengths [5].

$$\mathbf{l}_i = \mathbf{R}\mathbf{b}_i + \mathbf{p} - \mathbf{a}_i \quad (1)$$

wherel_i is i^{th} leg length ($i=1,2, ... ,6$)

p is desired center point of the mobile platform (p_x, p_y, p_z)

R is rotation matrix and defined as:

$$\mathbf{R} = \begin{bmatrix} U_x & V_x & W_x \\ U_y & V_y & W_y \\ U_z & V_z & W_z \end{bmatrix} \quad (2)$$

$\mathbf{b}_i$ is i^{th} node of the base platform (b_{ix}, b_{iy}, b_{iz})

$\mathbf{a}_i$ is i^{th} node of the moving platform (a_{ix}, a_{iy}, a_{iz})

The rotation matrix **R** is the transformation from orientation (defined by azimuth and elevation angles) to hexapod coordinate and it elements are defined as follows [6]:

$$\begin{aligned}
Ux &= \cos(-Az)\cos(90 - El)\cos(Az) - \sin(-Az)\sin(Az) \\
Uy &= -\sin(-Az)\cos(90 - El)\cos(Az) - \cos(-Az)\sin(Az) \\
Uz &= -\sin(90 - El)\cos(Az) \\
Vx &= \cos(-Az)\cos(90 - El)\sin(Az) + \sin(-Az)\cos(Az) \\
Vy &= -\sin(-Az)\cos(90 - El)\sin(Az) + \cos(-Az)\cos(Az) \\
Vz &= -\sin(90 - El)\sin(Az) \\
Wx &= \cos(-Az)\sin(90 - El) \\
Wy &= -\sin(-Az)\sin(90 - El) \\
Wz &= \cos(90 - El)
\end{aligned} \quad (3)$$

Where:$Az$is Azimuth angle (degree)

El is Elevation angle (degree)

After the mathematical computation is completed in the above steps, the controller drives the actuators to the desired positions. The control is performed by selected PID (Proportional Integral Derivative) and feedbacks from the optical encoders [5] and [7].

III. DESIGN AND DEVELOPMENT OF VNREDSAT-1 HEXAPOD CONTROLLER

The hardware design of the controller is selected based on Mitsubishi products including 1KW servo motors and theirs compatible drives programmable logic controller (PLC) and motion controller [9]. This selected solution guarantees synchronous control and monitoring of the six actuators with emergency stop and alarms. The software development for the controller is supported by professional tools such as IX developer, MELSOFT GX Work.

Fig 4VNREDSat-1 hexapod control system

The software of the controller is designed with 02 key modules:

Kinematic module receives satellite orbit or pointing direction from the VNREDSat-1 satellite control station, calculate the motion trajectory of the antenna and solve the inverse kinematics problem. The output of the module is the current lengths and joint velocities of the six hexapod actuators. The module flow chart is illustrated in Figure 5.

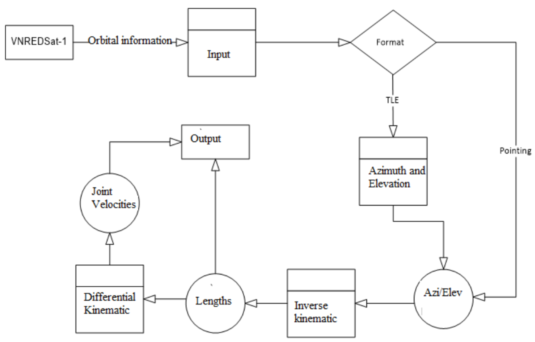

Fig 5 Flow chart of the kinematics module

Control module performs solving of the dynamic problems, calculation of the PID controller. The input of the module is the output values from the kinematics module and the output of the module is the actuator control values.

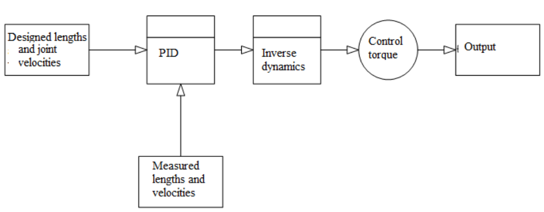

Fig 6 Flow chart of the control module

The control software is implemented by motion PLC and motion controller and MELSOFT MT Developer2 and MELSOFT GX Works2 for programming. The program drives six linear actuators of the hexapod in synchronous manner. Monitoring and alarm functions are also integrated in the control software to ensure the safety of the system. Additionally, user interface is supported by HMI IX Developer [8].

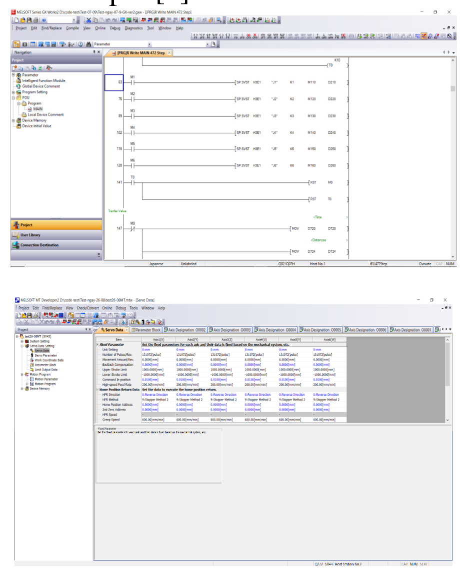

Fig 7 Interfaces by MELSOFT for control software

Orbit calculation and hexapod control interface are depicted in the figure 8:

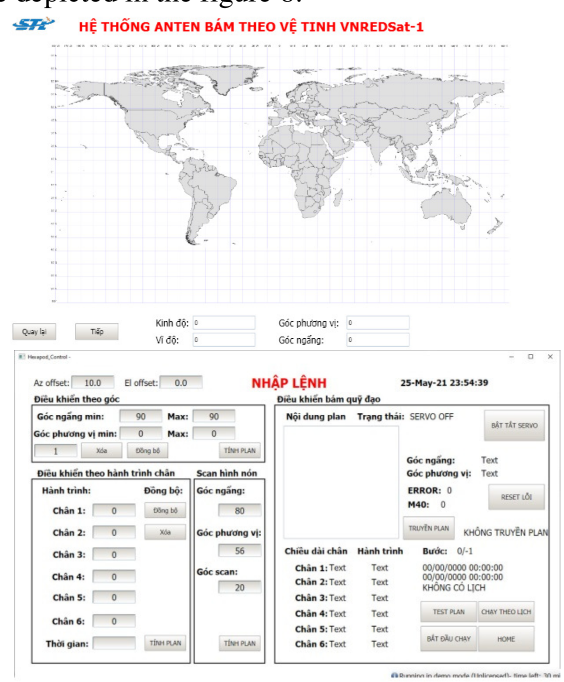

Fig 8User interface for VNREDSat-1 orbit calculation and hexapod control and monitoring

IV. EXPERIMENT RESULTS

The controller is used to control the hexapod structure in azimuth and elevation angles. First experiment is performed to maneuver the antenna in 01 full rotation (360 degree in azimuth). Delta 1 to 6 is the displacements of each linear actuator (in millimeters) are shown in figure 9.

The measured position of each leg during the experiment is depicted in figure 10.

The experiment results demonstrate the smooth performance of the designed controller and control software. The hexapod structure can be controlled in azimuth and elevation angles to point its mobile platform toward a designed orientation which follow the VNREDSat-1 satellite in orbit.

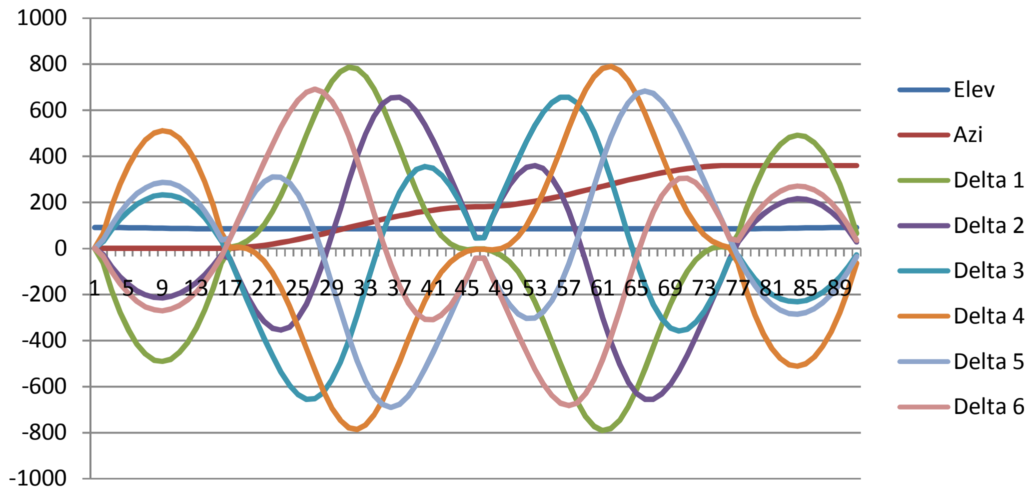

Fig 9 Calculation results for 360 degree azimuth control (leg displacements in mm)

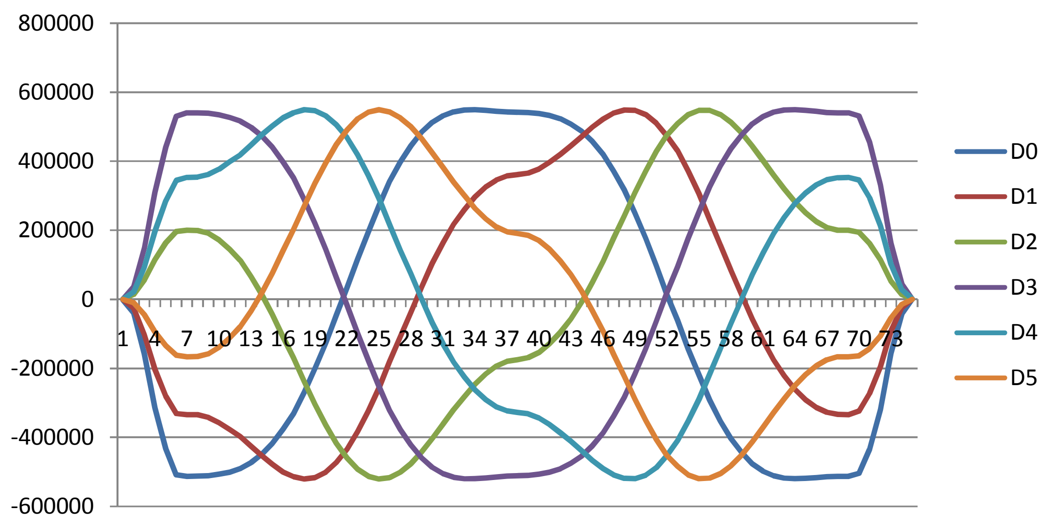

Fig 10 Measured lengths of the hexapod actuators ($x10^{-4}$mm)

V. CONCLUSIONS

The article presented the hardware and software design of the controller for hexapod structure. The antenna is installed on the moving platform of the hexapod. The orientation of the antenna is maneuverered by the controller following VNREDSat-1 satellite. The controller software is composed of the kinematics and control modules and interface properly with the mechanism. The control accuracy and reliability are acceptable for VNREDSat-1 tracking but they may suffer from degraded performance due to environment impacts on the mechanical parts. This should be considered in the further research

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