Control system for automatic positioning of a satellite antenna

Edgar Roberto Ramos Silvestre, Eynar Calle Viles, Isabel Morales Ledezma

Universidad Privada del Valle UNIVALLE., Bolivia
eramoss@univalle.edu ; eynarcalle@gmail.com; Isabel.morales.le@gmail.com

Abstract. This work proposes a control system for automatic positioning of a satellite antenna. The mathematical model of a DC motor is explained and the simulation of the entire system is demonstrated. Likewise, is mentioned the control method used in the system and the different reactions of the prototype. Also, the electronics modules and hardware modules are explained. Finally, the test acquired with the prototype is shown with a DVB S-2 system. The entire simulation software is developed in Matlab, a portable software designed to perform different parameters such as elevation, azimuth and polarization LNB for a satellite link.

Keywords: satellite link, elevation, azimuth, DVB S-2.

1 Introduction

Nowadays, satellites play an important role in global communication including phones, data networks, video streaming and transportation, as well as the television and radio diffusion straight to the user [1].

Satellite communication offers significant advantages over other types of long-distance communication. To mention some, the ability to communicate between two or more points at considerable distances; the ability to disseminate and collect signals on any ground surface with direct line of sight; and the ability to transport services to remote regions without using wired media, where point to point connection would not be practical to implement the links.

Satellites are used extensively for communication purposes as well as in navigation systems, scientific research, data capture remotely, military reconnaissance, detection of natural disasters, tele-education, tele-health or any other application. All these applications require one or more direct communication links with the satellite [2].

Moreover, it is observed that control earth stations of great magnitude, have a system of motors to control a satellite dish. So from the beginning of the appearance of these electric actuators, there is a need to control its position, speed and acceleration for generating a controlled motion, in mechanisms [4].

The use of electric motors has led to the use and development of control schemes from the simplest to those considered modern control techniques using feedback

sensors for measurements of variables associated with the system. Constantly aiming to improve the performance of engines, new topologies and control methods are developed.
For correct alignment of an antenna with a satellite three movements called azimuth, elevation and polarization are required. The first two will be of interest for the project to control the movement of the antenna. In this article a simple ON / OFF control and easy to handle, with respect to a PID controller is proposed.

2 Mathematical model and control law

2.1 Mathematical model of a DC motor

In Figure 1, a DC motor moves a load through a box of gears. This load represents a parabolic antenna which obtains geostationary satellite signal through movements in azimuth and elevation. To perform the movement of azimuth on the satellite dish, a DC motor is used; and another for movement in elevation. Thus, it can be controlled an earth station.

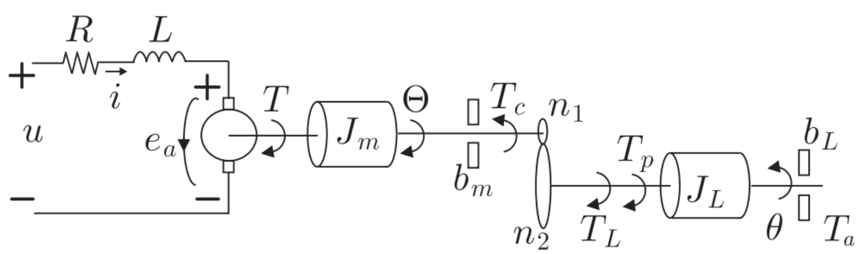


Fig. 1. DC motor, which drives a load through gears n1 and n2 where n2 represents the support of the parabolic antenna, a gear with 86 teeth; and n1 represents the motor's gear that corresponds to an endless screw.

The mathematical model of the DC motor is resumed from [5] where an electrical and mechanical subsystem is presented.

Electrical subsystem model

When applying Kirchhoff's Voltage Law to the armature circuit that is shown in Figure 1, it results:

$$applied\ voltage = \sum brownouts\ in\ the\ grid$$

$$u = voltage\ drop\ across\ the\ inductor + voltage\ drop\ across\ the\ resistor + counter\ electromotive\ force$$

$$u = L\frac{di}{dt} + R\,i + e_a$$
$$e_a = k_e\,\dot{\Theta} \quad (1)$$

Where "$\dot{\Theta}$" represents the first time derivative of the variable.

Mechanical subsystem model of the DC motor

In this sector, it should be applied the second law of Newton. As there are two different bodies, Newton's second law should apply to each of these bodies separately.

Rotor model:

$$Inertia * angular\ acceleration = \sum Torque\ J_m$$

$$J_m\ddot{\Theta} = torque\ generated - friction - load\ torque.$$

$$J_m\ddot{\Theta} = T - b_m\dot{\Theta} - T_c$$
$$T = k_m i \quad (2)$$

Load model:

Before applying Newton's second law to the load some important relationships, motor gears and gears of the load are determined,

$$n = \frac{n2}{n1}\ ; \qquad T_L = nT_c\ ; \quad \Theta = n\theta \quad (3)$$

Now it can be applied Newton's second law to the load:

$$J_L\ddot{\theta} = T_L - b_L\dot{\theta} \quad (4)$$

From (1) and (2) - (3), the combined model of the DC motor and the load is obtained:

$$J_m\ddot{\Theta} = k_m i - b_m\dot{\Theta} - \frac{1}{n}T_L$$
$$J_m\ddot{\Theta} = k_m i - b_m\dot{\Theta} - \frac{1}{n}\left(J_L\ddot{\theta} + b_L\dot{\theta}\right)$$

$$J_m \ddot{\theta}\, n = k_m i - b_m \dot{\theta} n - \frac{1}{n}\left(J_L \ddot{\theta} + b_L \dot{\theta}\right)$$
$$(J_m n^2 + J_L)\ddot{\theta} + (n^2 b_m + b_L)\dot{\theta} = n\, k_m i \tag{5}$$

If is defined:

$$J = n^2 J_m + J_L \qquad b = n^2 b_m + b_L \tag{6}$$

Then:

$$J\ddot{\theta} + b\dot{\theta} = n\, k_m i \tag{7}$$

Finally, the mathematical model of the DC motor is given by (1) and (7), which expressed in terms of axis angular velocity $\varpi = \dot{\theta}$ are defined as:

$$L\frac{di}{dt} = u - R\, i - k_e\, n\, \varpi$$

$$J\frac{d\varpi}{dt} = -b\, \varpi + n\, k_m i \tag{8}$$

2.2 Control law

The evolution of modern storage electronic equipment and processing of data, enables the improvement in control systems. Thus, they can be implemented in microcontrollers for motor control. This is very important in any mechatronic system, and imposes challenges that defy designers based on control theory controls. Traditionally motors were controlled manually, the modern control came with semiconductors, subsequent developments in power electronics and microelectronics allowed the development of better drivers with high performance and cheaper components.

Currently, new electronic devices, microprocessors, microcontrollers and digital signal processors are developed, which allow the evolution of more sophisticated and economic controls.

In this article a simple and economical ON / OFF control, implemented in a microcontroller ATMEGA 328 is proposed, which is simulated in Matlab Simulink based on the mathematical model of the DC motor. Figure 2 shows that the ON / OFF control is connected to the DC motor and feeds back the position variable of the DC motor controller. In addition, it can be implemented with low cost electronics covering all the needs of the system.

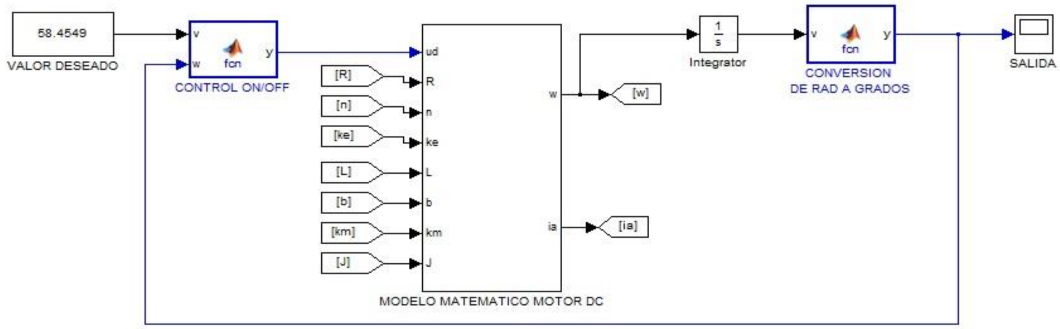


Fig. 2. Design of a DC motor controller, using an ON/ OFF controller which positions the system in the required direction.

2.3 Simulation

Once the mathematical model of the DC motor is known and the parameters involved as: resistance R, inductance L, viscous friction b_m, rotor inertia J_m, gear ratio n, back electromotive force k_(e)and constant torque motor k_m, it are parameters characterizing a DC motor, a series of experiments performed allowed the observation of the different reactions of the DC motor. In Figure 3, the parameters used to perform the simulation are shown as well as the DC motor plotting of equation (8) obtained from the mathematical model of the DC motor.

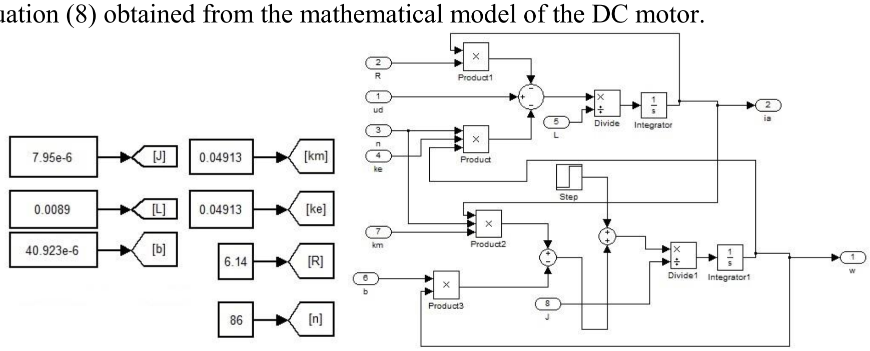


Fig. 3. (a) DC motor parameters, these parameters allow the DC motor recreate in a simulation environment, (b) Matlab-Simulink representation of the mathematical model of the DC motor.

Matlab is a working environment for scientific computing with a Simulink extension that is used to model, simulate and analyze localization system [6].

In Figure 4, the interface of simulation designed is observed; theoretical and practical tests were performed with the Bolivian satellite Tupac Katari that allowed to achieve and analyze the different reactions of the system.

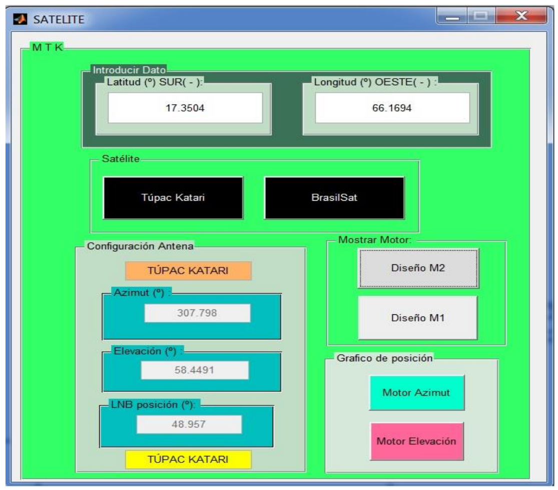


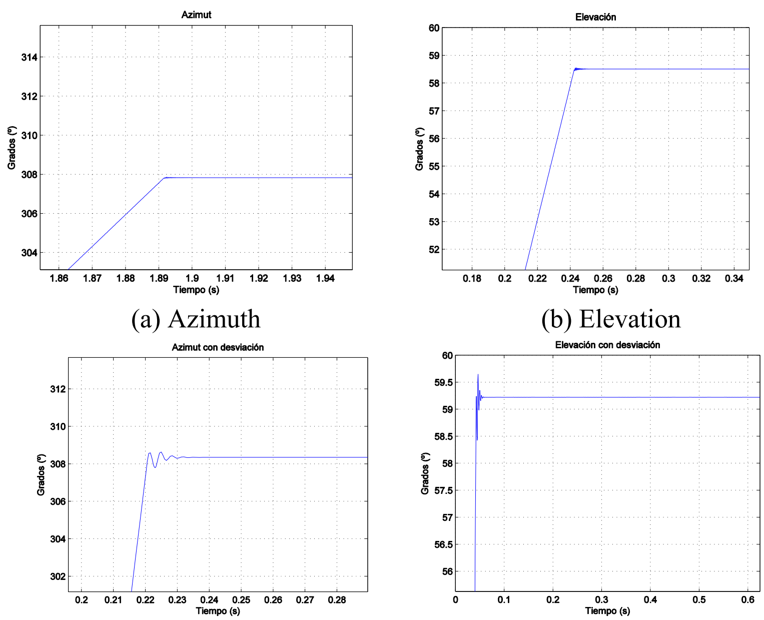
Fig. 4. Simulation software has a graphical user interface (GUI), where it can graphically analyze the results.

When entering data as latitude and longitude position, it is possible to determine the elevation and azimuth that are required for a satellite link. With the simulation software it is possible to calculate these parameters.

With the mathematical model of the DC motor, using standard values as shown in Figure 3, you can get the simulation of a DC motor by pressing the "Motor azimut" (motor azimuth) button and "Motor elevación" (motor lift). In Figure 4, the system response is obtained.

Figure 5, shows the response of the DC motor in azimuth, it is observed the position acquired by the DC motor after being controlled. To achieve this response in azimuth, was used n2=86 and n1=1. Where n1 represents an endless screw and n2, a 86 teeth gear. For testing in elevation, was used n1=1 and n2=58, so that n1 also represents an endless screw, and n2, a 58 teeth gear.

In the simulation it is required to position the elevation system with 307.79 degrees and an azimuth of 58.45 degrees respectively. In Figure 5, (a) and (b) show that the system is positioned in the calculated data, but a variation is observed in the system (c). If the values of n1 and n2 are changed, the system responds differently. Was achieved the variation n = 20 according to equation (3), where also was determined that increasing the number of teeth n1, the system becomes unstable and introduces error in the final result.



(a) Azimuth (b) Elevation

(c) Azimuth deviation (d) Elevation deviation

Fig. 5. (a) DC motor response in azimuth, (b) DC motor response in elevation, (c) DC motor response with azimuth deviation, (d) DC motor response with elevation deviation.

3 Mechanics structure and hardware

3.1 Structure of satellite antenna

To build the prototype, the pieces were designed with SolidWorks software. A satellite dish offset type was used with: 65cm a major axis and a minor axis of 60 cm, an angle offset 22.61º, a gain of 36.65db Ku-band reflector to 12.5GHz and an efficiency of 75% [3].

It is necessary that the structure is well designed so not to have variations when the system is running. Consequently, for the development of each of the prototype parts, rigid materials were used.

Figure 6, shows the design of the main axis corresponding to the azimuth prototype, this piece was made to fit and with plastic material. Contains a gear (for simulation corresponds to the azimuth motor, n2) of 86 teeth which allows to obtain precision when the prototype is operating.

Also, the DC motor with an incremental encoder adapted to an endless screw is observed (for simulation corresponds to n1). This screw was produced to fit as and in plastic material.

Fig. 6. (a) DC motor with endless screw, equivalent to n1=1, (b) Principal axis equals n2 = 86. The DC motor uses an incremental encoder, resolution 400 pulses.

By considering that the worm is equivalent to a gear having a single tooth, this helps in system accuracy. It also generates a resting state system, preventing the main axis to move when this is out of operation for any disturbance.

3.2 Electronic boards

Three electronic modules were implemented, each controlled by a development board that works as a master. Each module, performs work independently so that the system can perform multiple processes using an integrated development environment. Each of the electronic modules are connected by a i2c interface. This allows independent control and perform multiple processes, each module has its own address so it can be identified in the system.
The master controller is an Arduino Uno, after being processed by the electronic modules, is responsible for performing queries and receive information. Furthermore, the designs of these three electronic modules are shown in Figure 7. They were developed independently, so that each module corresponds to a printed circuit board that can function as an expansion, this allows the system to be scalable.

(a) Módulo electrónico sensores

(b) Módulo electrónico elevación y azimut

(c) Módulos electrónicos ensamblados

Fig. 7. (a) Electronic sensor module, is responsible for feeding the modules that are connected, as well as support to the sensors 10DOF IMU and GPS. (b) Electronic module elevation and azimuth, is responsible for performing the position control of DC motor, using microcontroller ATMEGA 328p. (c) Assembled electronic modules.

Using Microsoft Visual Studio, integrated development environment for Windows operating systems, a program is developed to be run as an application with a user interface on a computer.

When entering latitude and longitude parameters, the necessary data are calculated: elevation, azimuth and angle of the LNB to direct a parabolic antenna to the satellite Túpac Katari.

Likewise, it can connect with the prototype and get the latitude and longitude parameters acquired by the GPS, and achieve calculate the elevation data, azimuth and angle of the LNB in the position where the prototype is located.

The application contains a graphical interface as shown in Figure 8, where can be observed the values calculated with data of latitude (-17.3504) and longitude (-66.1694), different tests were performed at place.

3.3 Software

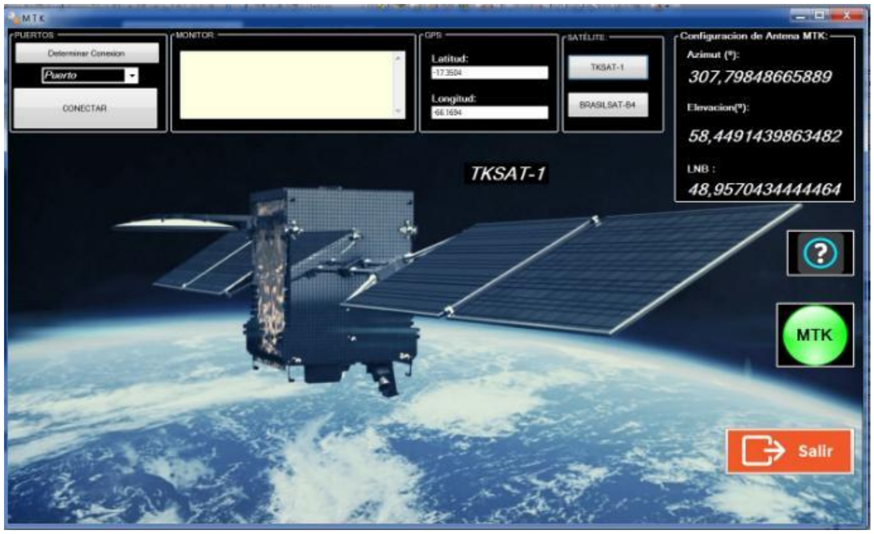


Fig. 8. Software user interface, application to calculate parameters of azimuth, elevation and polarization of LNB.

4 Results

A variety of tests were conducted in Bolivia. Especially in different parts of the city of Cochabamba, these test points correspond to:

- Point 1 Latitude -17.3504 Longitude -66.1694 (Cochabamba, North Zone)
- Point 2 Latitude -17.3303 Longitude -66.2257 (Cochabamba, Tiquipaya, Universidad del Valle)
- Point 3 Latitude -17.4059 Longitude -66.0333 (Cochabamba, Sacaba)

Among the tests, it is accomplished a signal strength of 84%, and a signal quality of 77%. In addition, it manages to capture 20 FTA channels from satellite Túpac Katari. In Figure 9, the result of the tests is shown. It is observed that the test performed number 197 corresponds to 317° azimuth antenna, maximum values acquired by satellite link. In addition, is detected ± 4 degrees for fine adjustment, this due to the radiation power of the satellite on Bolivian territory, 54.5dbW that allows the system to acquire the signal at any position within this range, to make an adjustment.
In Figure 10, the final prototype stands out, performing tests in 2. The prototype is fully portable with economically affordable and easily accessible materials in the local market.

Decima Prueba (pos2)			
Prueba	**Grados (º)**	**Intensidad de Señal (%)**	**Calidad de Señal (%)**
190	310	44	5
191	311	44	5
192	312	44	5
193	313	87	58
194	314	87	71
195	315	87	71
196	316	84	76
197	317	84	77
198	318	84	76
199	319	84	76
200	320	85	74
201	321	86	71
202	322	44	7
203	323	44	5
204	324	44	5
205	325	44	5
206	326	44	5
207	327	44	5
208	328	44	5
209	329	44	5
210	330	44	5

Fig. 9. Results Table, in the test number 197 is possible to obtain a signal strength of 84% (intensidad de señal), and a signal quality of 77% (calidad de señal).

Fig. 10. Final prototype, performing tests with a DVB-S2 receiver with a frequency of 11670 MHZ, symbol rate of 150000 Ksps and vertical polarization.

5 Conclusions

It was experienced automatic control laws on DC motors in order to obtain the correct position of azimuth and elevation with a satellite dish. In addition, it was reached to make a satellite link with 20 free channels Tupac Katari satellite from Bolivian property.

It was also possible to design electronic and software modules necessary for geostationary satellite location of the Tupac Katari. The final prototype with all modules was implemented by testing and calibration of the system in three locations corresponding to Tiquipaya, Zona Norte and Sacaba in Cochabamba, Bolivia.

A simulation software was performed to observe the reactions of the controller, as well as the entire system. Furthermore, an application was developed to interact with the user.

By performing several tests with the prototype implemented, it was possible to note a variation of 8 degrees, to fine-tune. In the same way, it was possible to observe that using an incremental encoder of 400 pulses per revolution in a dc motor with an endless screw and a 86 teeth gear: got higher resolution and stability in the project. That is, 34,400 pulses per revolution (360 ° 0 °) therefore, the result is more accurate.

It is possible to obtain Túpac Katari satellite signal with a DVB-S2 receiver, to appreciate free channels.

An installation of an offset type Ku-band parabolic satellite may take several hours to even days, if not aware of essential parameters to perform an installation. This project, reduces installation time, providing ease and portability when is time to make an installation.

6 References

1. Gérard Maral, M. B. (2009). *Satellite Communications Systems, Techniques and Technology* (quinta ed.). John Wiley & Sons Ltd.
2. Justino Ribeiro, J. A. (2008). *Propagación de ondas electromagnéticas,principios y aplicaciones.* São Paulo: Érica.
3. Motta Marins, C. N. (2004). *Estudo analítico e numérico de um enlace digital de comunicaçao via satélite em condiçao orbital geoestacionária.* Santa Rita do Sapucaí.
4. Tafoya Sánchez, J. J. (2010). *Control de velocidad angular de motores de corriente directa mediante ténicas de control automático.* Mexico, D.F.
5. Orbegoso Guerrero, A., Muños Villalobos, C., & Villalta Ramirez, A. (2010). *Software para ciencia e ingeniería MATLAB.* Lima-Perú: Macro E.I.R.L.
6. Justino Ribeiro, J. A. (2012).*ENGENHARIA DE ANTENAS, Fundamentos, Projetos e Aplicaçoes.* Sâo Paulo: Érica.