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SYMBOLIC MODELING OF A TRACKING RADAR GIMBAL SYSTEM OF AN AIRCRAFT

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ABSTRACT

In multibody mechanics with kinematics problems, the motion analysis for a platform can be classified into two cases: the forward kinematics and the inverse kinematics problems. For the forward kinematics problem, the trajectory of a point on a mechanism is computed as a function of the joint motions. In the inverse kinematics case, the goal is to compute the joint motions necessary to achieve a prescribed end effectors’ trajectory. A system for tracking a target comprises an acquisition sight used by a pilot of an aircraft to acquire and track the target using a tracking handle. The tracking device’s azimuth and elevation on sight, track handle, video tracking system or tracking radar coupled to an infrared display system is processed by a computer to provide azimuth and elevation angle signals to a gimbal mirror interface which steers the gimbaled mirror to the target. This paper presents a kinematics of a tracking radar gimbal using symbolic technique. The model was built and simulated using MapleSim and the obtained result signify that altitude and orientation angle is determinable when tracking a desired target.

Keywords: Azimuth, Kinematics, MapleSim, Trajectory, Tracking radar gimbal

1. INTRODUCTION

In a multibody mechanics kinematics, problems are usually categorized into forward and inverse kinematics. The forward kinematics problem trajectory of a point on a mechanism (the end effectors’ of a robot arm or the center of a platform support by a parallel link manipulator) is computed as a function of the joint motions. In the case of an inverse kinematics problem, the goal is to compute the joint motions necessary to achieve a prescribed end effectors’ trajectory (Goossens & Richard, 2013). In using a symbolic solution to the inverse kinematics problem, code generation is made easier and can be embedded in real-time Hardware-In-the-Loop (HIL) applications.

The word radar was a compound word coined from; “radio detection and ranging”. Its development as a primary tracking device in Europe and U.S accelerated independently in the mid and late 1930s (Bureau, 2013). In 1903 and 1904, a

German engineer Christian Huelsmeyer was the first person that used radar principles to build a simple ship detection device to avoid ship collision in fog. However, the radar technology became wide spread for military purpose in World War II (Bureau, 2013). Radar finds application in a highly diverse field which include air and terrestrial traffic control, radar astronomy, air-defence system, meteorological precipitation monitoring, flight control system, digital signal processing, machine learning, public health surveillance and much more (Liu *et al.*, 2011). A gimbal is a pivoted support that allows the rotation or free inclination in any direction or suspension of an object about a single axis, which finds many application, out of which are inertia navigation, rocket engines, photography and imaging, film and video and marine chronometers.

Goossens & Richard (2013) presented a work using symbolic technology to derive inverse kinematics solutions for actuator control development. Deng & Zou (2013) used simulation of stable tracking control for gimbal of phase array seeker. Saini & Hablani (2014) proposed an air-to-air tracking performance with inertia navigation and gimbaled radar: a kinematic scenario. Adams *et al.*, (2014) developed a standoff range sense through obstruction radar system. Hong & Cho (2014) utilized a kinematics algorithm and robust controller design for inertially stabilized system. Rajesh & Kavitha (2015) utilized camera gimbal stabilization using conventional PID controller and evolutionary algorithm. Sahawneh *et al.*, (2015) proposed an airborne radar-based collision detection and risk estimation for small unmanned aircraft systems. Saini & Hablani (2015) presented an air-to-air tracking of a maneuvering target with gimbaled radar. Zhao *et al.*, (2016) developed a reusable modelling of pulsed Doppler radar seeker for coherent video signal simulation. Klepsvik *et al.*, (2016) used position reference system and method for positioning and tracking one or more objects.

This paper presents the kinematics of a tracking radar gimbal using symbolic technique. This was implemented in MapleSim which was build and simulated using MapleSim. The rest of the paper is organized as follows. Section 2 defines the model description and presents the model governing equations. Section 3 discusses the results obtained and finally, some concluding remarks are providing in section 4.

2. THE GIMBAL MODEL

In this section, the model description and related governing equations are discussed.

2.1 Model Description

In the tracking radar gimbal model discussed in this section, the required elevation and azimuth angles are determined for a radar tracking system. The inverse problem is solved using kinematic equations generated by MapleSim. Servo drives are implemented to tune the required parameters of the tracking gimbal.

a. Tracking: In general terms, tracking refers to the estimation of the position of a moving target. The target is followed independently in both range and angles for a better estimate. The developed model describes a tracking radar gimbal on an aircraft which uses two degree of freedom gimbal mechanism, elevation and azimuth, to position the dish to a point at selected target. This is typically located by a GPS that provides the latitude, longitude and altitude (XYZ) of the target. From its current position, the aircraft can approach the target at any point or location. It is also interesting to note that the required altitude and orientation is determined by azimuth and elevation angles. However, this is the most challenging aspect of the operation. If the topology of the mechanism, line of sight (LOS) between the radar dish and target are given and defined respectively, inverse kinematics (IK) is used to find the exact solution for the azimuth and elevation angles (Goossens & Richard, 2013). The position and angles (azimuth and elevation) of the components are shown in Figure 1.

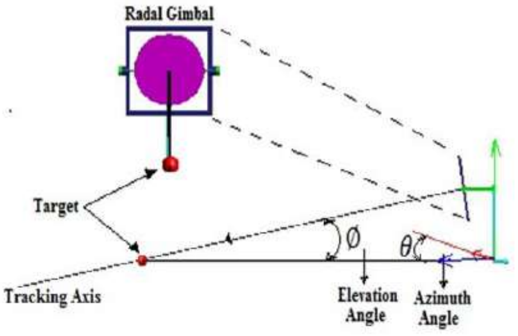

Figure 1: Elevation and Azimuth angle of Rader Gimbal

The components of Figure 1 display a model representative of real life components on a tracking field. In reality, the tracking exercise comprise of the following steps:

i. Track initiation: this involves creating tracks or a track, which is based on outstanding record of detection captured by the device. Meaning, once the tracker is running, only those hit that could not be associated with an existing track are to start new tracks.

ii. Data association: a track remains uncertain record. Hence, not displayed on the operators screen to avoid false track until an update is received in direct association with the outstanding track.

iii. Track smoothing: at this stage of tracking, the latest track prediction is combined with the associated hit to provide a new estimate of the target location.

iv. Track maintenance: this involves decision whether to terminate a track or not. It implies that, only a target that is not loss is chosen.

b. The Gimbal System: the role of the gimbal in the setup is to stabilize the sensors line of sight towards the target by isolating the sensor from the disturbance induced by the operating environment, such as disturbance torques and body motions. The following methods are employed in achieving solutions for a tracking radar gimbal of whose 2D model drawn on Maplesim platform is shown in Figure 2:

i. The joints are uniquely named to help identify the required variables when the equations of motion are generated.

ii. The constraints are explicitly included in the model to ensure that the required variable appear in the equation.

Items (i) and (ii) are achieved by setting the appropriate options for each of the joints.

The mechanism model is then created in MapleSim for accessibility in $Maple^{TM}$ and by using the multibody analysis tools, the equations of motion for the mechanism are then extracted

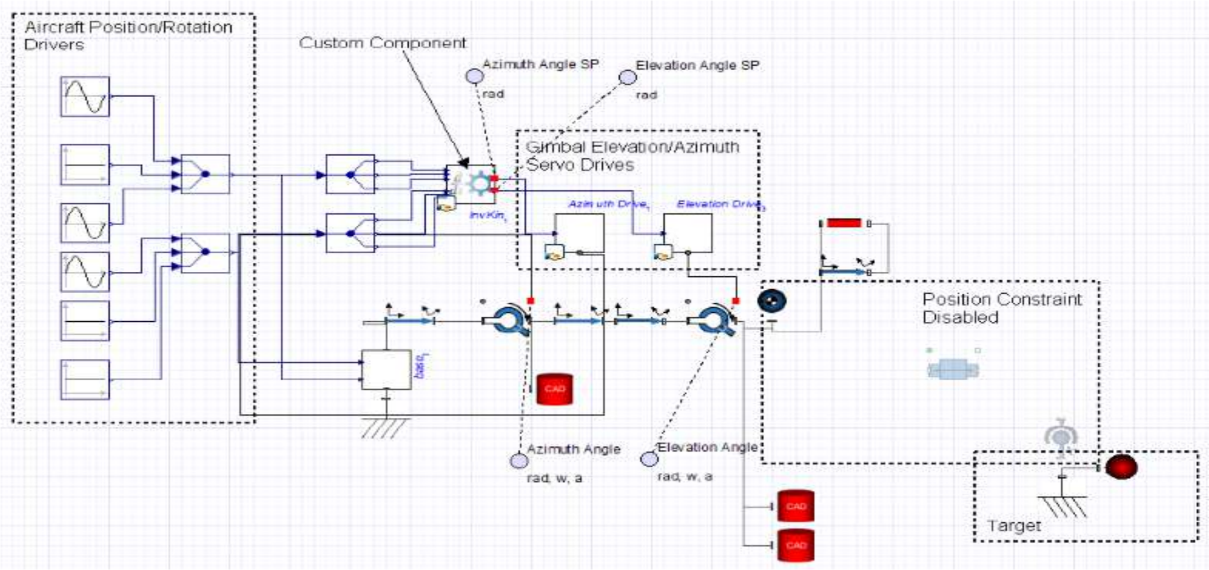

Figure 2: Tracking Rader Gimbal 2D model

2.2 Model Governing Equations

The constraints equation generated from the tracking radar gimbal 2D model are as follows:

$$f_i\left(\theta_{az},\theta_{el},\mathrm{r},\xi,\eta,\zeta\right)=0 \qquad (1)$$
$$i=1,2,\ldots$$

Where r is the vector (aircraft) body position and ξ,η,ζ are the body orientation angles. Also, θ_{az},θ_{el} were the azimuth and elevation angle of the gimbal respectively. The model's governing equation are generated from MapleSim platform as follows:

$$Raz\theta(t)+\frac{10}{11}Azimuth\_Drive\_LPID\_x(t)=0 \qquad (2)$$

$$-\frac{1}{11}Azimuth\_\mathrm{Drive\_LPID\_I\_y}(t)+\frac{1}{200}Azimuth\_Drive\_LPID\_Limiter\_u(t)=0 \qquad (3)$$

$$-\arctan\left(\frac{-2Tx+2P\_s\_ref(t)}{1+2Ty\sin\pi\_ref(t)-2Tz\cos\left(P\pi\_ref(t)\right)+2P\_\mathrm{s}\_ref\_(t)\cos\left(P\pi\_ref(t)\right)}\right)=0 \qquad (4)$$

$$\mathrm{Re}\,l\theta(t)+\frac{10}{11}Elevation\_Drive\_LPID\_\mathrm{D\_x}(t)=0 \qquad (5)$$

$$-\frac{1}{11}Drive\_LPID\_I\_y(t)+\frac{1}{200}Drive\_LPID\_Limiter\_u(t)=0 \qquad (6)$$

3. RESULTS AND DISCUSSION

The resulting plot of azimuth angle, acceleration, angular velocity and elevation angle obtained from the simulation carried out on the developed tracking radar gimbal model are shown in Figures 3, 4, 5 and 6 respectively,

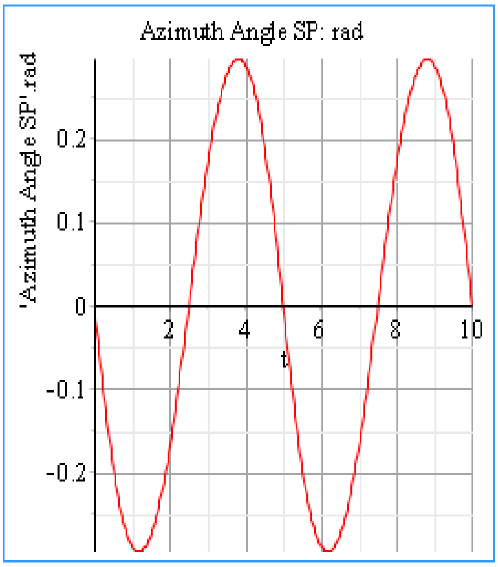

Figure 3: Azimuth Angle

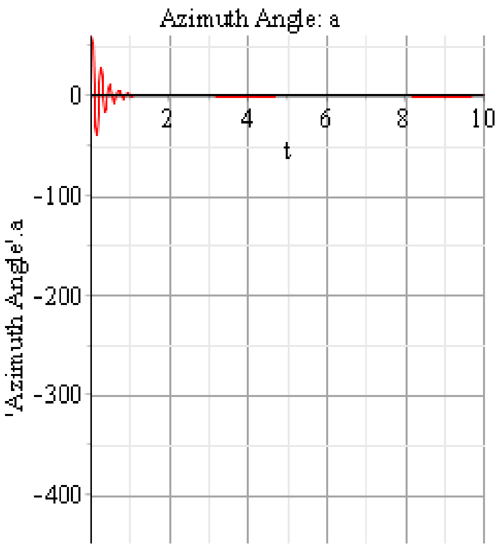

Figure 4: Acceleration

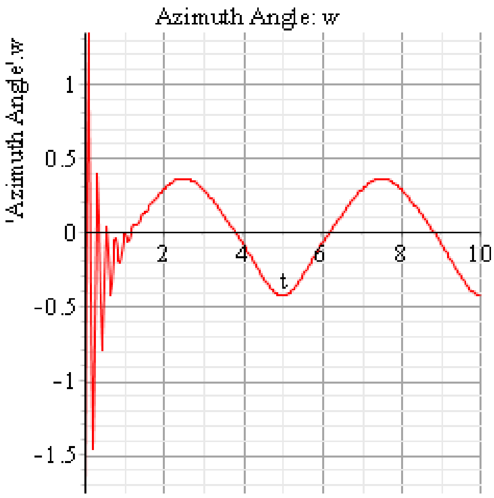

Figure 5: Angular Velocity

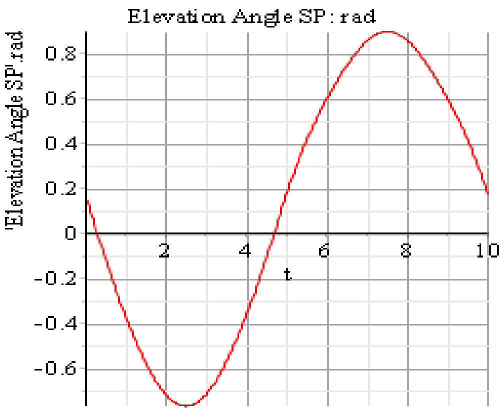

Figure 6: Elevation Angle

Figure 3 and 6 shows an azimuth angle and elevation angle plot maintaining a sinusoidal shape of waveform in which an exact pattern of trend is maintained over and over a period of 2.2 seconds interval for the azimuth angle and 4.4 seconds corresponding to the elevation angle signifying that altitude and orientation angle is determinable when tracking a desired target. Figure 4 shows an appreciable level of acceleration ascertaining pick up with little overshoot and settle within 1 seconds of motion. Finally, as regard the angular velocity of Figure 5, though having irregular angular representation for a limited time of 1 seconds, after which it settles giving a regular trend of sinusoidal shape over a period of 4 seconds amplitude gain and delay of 2 seconds resulting in amplitude lag and continuously in that phase.

4. CONCLUSION

Inverse kinematics is a highly advanced approach for solving motion planning problems. While there are many benefits in using an inverse kinematic approach, the difficulties in solving these problems manually mean that non-robust and iterative techniques are often used instead. In the model developed in this paper, the required elevation and azimuth angles are determined for a radar tracking system. This inverse kinematics problem is solved using kinematics equation generated by MapleSim. Servo drives were implemented in tuning the required parameters of the tracking gimbal. It should be noted that the same problem can also be solved numerically within MapleSim by applying enforced motion to the system by using a prescribed translation motion driver component. But such a purely numerical solution does not have the same flexibility as the symbolic solution presented in this paper. Using the symbolic solution obtained here and MapleSim code generation feature, efficient simulation codes can be obtained and embedded into other platforms, unlocking the possibility for real-time applications.

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