αβ filter for Spacecraft Attitude Estimation

Halima BOUSSADIA[1], ABDELKRIM MECHE[2], Mohammed Arezki SI MOHAMMED[3], Nabil BOUGHANMI[4]

[1,4]Lab of signals systems data, USTO-MB University; P.B 1505, Bir El Djir 31000, Oran Algeria
E-mail: halima.boussadia@univ-usto.dz, nabil.boughanmi@univ-usto.dz.

[2] LSI Laboratory, USTO-MB University; P.B 1505, Bir El Djir 31000, Oran Algeria
E-mail: abdelkrim.meche@univ-usto.dz

[3] Department of Research in Space Mechanics, Centre of Satellite Development, Oran 31000, Algeria
E-mail: masimohammed@asal.cds.dz

Abstract: Attitude estimation is considered a crucial technology in space research, as it is used to convert sensor measurements into estimated attitude using various methods. However, due to the computational constraints and complexity of space missions, most estimators tend to be computationally expensive and unsuitable for practical applications. This paper addresses this problem by proposing a new configuration for an on-board Attitude Determination and Control System (ADCS) based on in-orbit flight data, which combines the αβ filter and TRIAD algorithm. The primary objective of this configuration is to achieve both low computational cost and high accuracy simultaneously. To evaluate the performance of the proposed configuration, simulations were conducted and compared to the in-orbit attitude of Alsat-1, which was estimated using small Euler angles and the Extended Kalman Filter (EKF) implemented on-board. The results showed that the proposed configuration provides acceptable performance while reducing computational costs

Keywords: Spacecraft, State estimation, αβ filter, TRIAD Algorithm, Real data

1. INTRODUCTION

Nowadays, the spacecraft attitude control problem has attracted a great attention because of the development of aerospace technology (Crassidis et al, 2007). The primary requirement for the success of a satellite's mission is to control it in space, which necessitates knowledge of the satellite's attitude. Therefore, attitude determination and estimation are fundamental. Over the last three decades, state estimation theory for spacecraft systems has been extensively studied. A good survey of existing algorithms for spacecraft attitude determination and estimation can be found in (Crassidis et al, 2007). These algorithms are classified into three categories: attitude determination algorithms, attitude estimation algorithms, and nonlinear observers. Each algorithm has its advantages and disadvantages in terms of accuracy, computational efforts, and memory requirements. Several studies have provided comparative analyses of these algorithms (Mekky et al, 2013; Zamri et al, 2016; Si Mohammed et al, 2016). The choice of the best algorithm depends on the mission requirements during satellite design.

The most commonly used estimation method is the Kalman filter (KF) (Kalman, 1960), which has been widely used in recent years (Markley et al, 2005). To make the KF more efficient for real systems, the Extended Kalman filter (EKF) (Jazwinski, 1970) has been developed for nonlinear aerospace applications (Lefferts et al, 1982; Markley, 2003). Many studies have used the EKF for space research (Soken et al, 2014; Soken et al, 2012; Qiu et al, 2018; Arasaratnam et al, 2010). However, these methods suffer from high computational costs, which render them unsuitable for spacecraft estimation due to the difficulty of space missions and tight computational budgets. The contribution of this work is to address the aforementioned problem by proposing a new configuration for on-board attitude determination and control system (ADCS) implementation based on the combination of αβ filter and TRIAD algorithm using the concept of sensor fusion with Magnetometer and Sun-sensor. The simulation is based on the real flight data of sensors that were aboard Alsat-1, the first Algerian satellite built by Surrey Satellite Technology Ltd (SSTL), equipped with only two sensors (magnetometer and sun sensor) to provide attitude using the EKF. The proposed configuration reduces the computational load while ensuring high accuracy.

The proposed configuration is suitable for spacecraft applications because it has a low computational load, making it practical for use. This new configuration is based on the αβ filter, which has been used in various applications, such as intelligent vehicle (Trag and Chen, 2009), wireless systems (Sharma et al, 2011), face tracking (Donghe and Jinsong, 2009), and target tracking (Meche et al, 2013). However, to the best of our knowledge, this is the first time that the αβ filter has been applied to satellite attitude estimation. (Quang et al, 1996) developed this filter for spacecraft orbit determination only and did not use it for attitude determination.

The reason for selecting this configuration in our work is that the TRIAD and αβ filter algorithms are the simplest and easiest methods for implementation in satellite projects, and they have unmatched characteristics. With this configuration, the power concern can be resolved because the sensor load is divided between the sun sensor and magnetometer to TRIAD. Therefore, if one sensor does not operate, the other sensor can easily transfer attitude data. The combination of TRIAD with the αβ filter, which is a faster and less computationally loaded algorithm, results in fast data transfer and efficient sensor handling.

The paper is organized as follows: Section 2 presents the spacecraft attitude model, and Section 3 contains two subsections that describe the design of the attitude estimators for the linear spacecraft model. The obtained results are presented in the next section, and finally, Section 5 concludes the paper.

2. SPACECRAFT ATTITUDE LINEARIZED MODEL

In the following section, we provide a concise overview of the spacecraft attitude model, which is known for being nonlinear and challenging to manage. In order to facilitate the process, a linearization technique is applied to the model when the satellite is in motion with small angles. The spacecraft attitude equations consist of two types: dynamic equations and kinematic equations. The dynamic equations are responsible for describing the spacecraft's movement in the inertial frame, and can be expressed using the following equation (Wertz, 1991):

$$\mathbf{I}\dot{\boldsymbol{\omega}}_{\mathbf{s}}^{\mathbf{I}} = \mathbf{C}_{\mathbf{gg}} + \mathbf{C}_{\mathbf{ext}} - \boldsymbol{\omega}_{\mathbf{s}}^{\mathbf{I}} \times \left(\mathbf{I}\boldsymbol{\omega}_{\mathbf{s}}^{\mathbf{I}} + \mathbf{h}\right) - \dot{\mathbf{h}} \tag{1}$$

Where $\boldsymbol{\omega}_{\mathbf{s}}^{\mathbf{I}}$, $\mathbf{I}$, $\mathbf{h}$, $\mathbf{C}_{\mathbf{gg}}$ and $\mathbf{C}_{\mathbf{ext}}$ represent the angular velocity vector in the inertial farm, the moment of inertia, the wheel angular momentum vector, the gravity gradient torque vector and the external disturbance torque vector respectively.

The kinematic equations are defined as follows (Hashida, 2004),

$$\dot{\varphi}=\omega_{ox}\cos(\psi)-\omega_{oy}\sin(\psi) \tag{2.a}$$

$$\dot{\theta}=\left(\omega_{ox}\sin(\psi)+\omega_{oy}\cos(\psi)\right)\sec(\varphi) \tag{2.b}$$

$$\ddot{\psi}=\left(-\omega_0{}^2\gamma+\omega_0\frac{h_y}{I_z}\right)\psi+\frac{h_x}{I_z}\dot{\varphi}+\left(-\omega_0-\frac{h_y}{I_z}+\omega_0\gamma\right)\dot{\varphi}-\frac{\dot{h}_z}{I_z}+\frac{N_{mz}}{I_z}+w_z \tag{2.c}$$

$$\boldsymbol{\omega}_{\mathbf{s}}^{\mathbf{o}} = \boldsymbol{\omega}_{\mathbf{s}}^{\mathbf{I}} - \mathbf{A}\,\boldsymbol{\omega}_{\mathbf{0}} \tag{3}$$

Where,

φ, θ and ψ are roll, pitch and yaw respectively, the Euler rotation sequence used here is 2-1-3.

$\boldsymbol{\omega}_{\mathbf{0}} = \begin{bmatrix} 0 & -\omega_0 & 0 \end{bmatrix}^T$ is the orbital rate vector,

$\mathbf{A}$ is the direction cosine matrix (DCM), defined as follow,

$$\mathbf{A}=\begin{bmatrix} \cos\psi\cos\theta+\sin\psi\sin\varphi\sin\theta & \sin\psi\cos\varphi & -\cos\psi\sin\theta+\sin\psi\sin\varphi\cos\theta \\ -\sin\psi\cos\theta+\cos\psi\sin\varphi\sin\theta & \cos\psi\cos\varphi & \sin\psi\sin\theta+\cos\psi\sin\varphi\cos\theta \\ \cos\varphi\sin\theta & -\sin\varphi & \cos\varphi\cos\theta \end{bmatrix} \tag{4}$$

For small Euler angles, the direction cosine matrix can be approximated by:

$$\mathbf{A}=\begin{bmatrix} 1 & \psi & -\theta \\ -\psi & 1 & \varphi \\ \theta & -\varphi & 1 \end{bmatrix} \tag{5}$$

Substituting Eq.(4) into Eq.(3)

$$\begin{aligned} \omega_{ox} &= \omega_x + \omega_0\cos\varphi\sin\psi \\ \omega_{oy} &= \omega_y + \omega_0\cos\varphi\cos\psi \\ \omega_{oz} &= \omega_z - \omega_0\sin\varphi \end{aligned} \tag{6}$$

Substituting Eq.(6) into Eq.(2)

$$\begin{aligned} \dot{\varphi} &= \omega_x\cos(\psi)-\omega_y\sin(\psi) \\ \dot{\theta} &= \left(\omega_x\sin(\psi)+\omega_y\cos(\psi)\right)\sec(\varphi)+\omega_0 \\ \dot{\psi} &= \omega_{oz}+\left(\omega_x\sin(\psi)+\omega_y\cos(\psi)\right)\tan(\varphi) \end{aligned} \tag{7}$$

For small Euler angles, the inertial angular velocity is expressed as follows,

$$\begin{aligned} \omega_x &= \dot{\varphi}-\omega_0\psi \\ \omega_y &= \dot{\theta}-\omega_0 \\ \omega_z &= \dot{\psi}-\omega_0\varphi \end{aligned} \tag{8}$$

Substituting Eq.(8) into Eq.(1) gives:

$$\ddot{\varphi}=\left(4\omega_0{}^2\alpha+\omega_0\frac{h_y}{I_x}\right)\varphi-\frac{h_z}{I_x}\dot{\theta}+\left(\omega_0+\alpha\omega_0+\frac{h_y}{I_x}\right)\dot{\psi}-\frac{\dot{h}_x}{I_x}+\omega_0\frac{h_z}{I_x}+\frac{N_{mx}}{I_x}+w_x \tag{9.a}$$

$$\ddot{\theta}=-\omega_0\frac{h_x}{I_y}\varphi-3\omega_0{}^2\beta\theta-\omega_0\frac{h_z}{I_y}\psi+\frac{h_z}{I_y}\dot{\varphi}-\frac{h_x}{I_y}\dot{\psi}-\frac{\dot{h}_y}{I_y}+\frac{N_{my}}{I_y}+w_y \tag{9.b}$$

$$\ddot{\psi}=\left(-\omega_0{}^2\gamma+\omega_0\frac{h_y}{I_z}\right)\psi+\frac{h_x}{I_z}\dot{\varphi}+\left(-\omega_0-\frac{h_y}{I_z}+\omega_0\gamma\right)\dot{\varphi}-\frac{\dot{h}_z}{I_z}+\frac{N_{mz}}{I_z}+w_z \tag{9.c}$$

$\boldsymbol{\omega}_{\mathbf{s}}^{\mathbf{o}} = \begin{bmatrix} \omega_{ox} & \omega_{oy} & \omega_{oz} \end{bmatrix}^T$ is the angular velocity vector in the orbital frame.

$\mathbf{h} = \begin{bmatrix} h_x & h_y & h_z \end{bmatrix}^T$ is the wheel angular momentum vector;

The state vector is a six-dimensional that combines the three-element attitude vector with the three-element angular rates vector such that:

$$\mathbf{X}=\begin{bmatrix}\varphi & \dot{\varphi} & \theta & \dot{\theta} & \psi & \dot{\psi}\end{bmatrix}^T \tag{10}$$

The set of equations Eq.(9) can be written as follows:

$$\dot{x}_1=x_2 \tag{11.a}$$

$$\dot{x}_2=\left(4\omega_0^2\alpha+\omega_0\frac{h_y}{I_x}\right)x_1-\frac{h_z}{I_x}x_4+\left(\omega_0+\alpha\omega_0+\frac{h_y}{I_x}\right)x_6-\frac{\dot{h}_x}{I_x}+\omega_0\frac{h_z}{I_x}+\frac{N_{mx}}{I_x}+w_x \tag{11.b}$$

$$\dot{x}_3=x_4 \tag{11.c}$$

$$\dot{x}_4=-\omega_0\frac{h_x}{I_y}x_1-3\omega_0^2\beta x_3-\omega_0\frac{h_z}{I_y}x_5+\frac{h_z}{I_y}x_2-\frac{h_x}{I_y}x_6-\frac{\dot{h}_y}{I_y}+\frac{N_{my}}{I_y}+w_y \tag{11.d}$$

$$\dot{x}_5=x_6 \tag{11.e}$$

$$\dot{x}_6=\left(-\omega_0^2\gamma+\omega_0\frac{h_y}{I_z}\right)x_5+\frac{h_x}{I_z}x_2+\left(-\omega_0-\frac{h_y}{I_z}+\omega_0\gamma\right)x_2-\frac{\dot{h}_z}{I_z}+\frac{N_{mz}}{I_z}+w_z \tag{11.f}$$

The satellite linearized model will be represented in the state space form as follows,

$$\begin{cases}\dot{\mathbf{X}}(\mathbf{t})=\mathbf{AX}(\mathbf{t})+\mathbf{BU}(\mathbf{t})+\mathbf{w}(\mathbf{t})\\ \mathbf{Y}(\mathbf{t})=\mathbf{HX}(\mathbf{t})+\mathbf{DU}(\mathbf{t})+\mathbf{v}(\mathbf{t})\end{cases} \tag{12}$$

Where,

$\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$ and $\mathbf{D}$ are state matrix, input matrix, output matrix and direct transition matrix respectively;

$\mathbf{x}(\mathbf{t})$ is the state vector;

$\mathbf{u}(\mathbf{t})$ is the command vector;

$\mathbf{y}(\mathbf{t})$ is the output vector;

$\mathbf{w}(\mathbf{t})$ and $\mathbf{v}(\mathbf{t})$ are the process and the measurement noise vectors, respectively.

The matrices $\mathbf{A}$, $\mathbf{B}$ and $\mathbf{C}$ are given by:

$$\mathbf{A}=\begin{bmatrix}0 & 1 & 0 & 0 & 0 & 0\\ \left(4\omega_0^2\alpha+\omega_0\frac{\mathbf{h}_y}{\mathbf{I}_x}\right) & 0 & 0 & \frac{\mathbf{h}_z}{\mathbf{I}_x} & 0 & \left(\omega_0+\alpha\omega_0+\frac{\mathbf{h}_y}{\mathbf{I}_x}\right)\\ 0 & 0 & 0 & 1 & 0 & 0\\ \omega_0\frac{\mathbf{h}_x}{\mathbf{I}_y} & \frac{\mathbf{h}_z}{\mathbf{I}_y} & -3\omega_0^2\beta & 0 & -\omega_0\frac{\mathbf{h}_z}{\mathbf{I}_y} & -\frac{\mathbf{h}_x}{\mathbf{I}_y}\\ 0 & 0 & 0 & 0 & 0 & 1\\ 0 & \frac{\mathbf{h}_x}{\mathbf{I}_z} & 0 & 0 & \left(-\omega_0^2\gamma+\omega_0\frac{\mathbf{h}_y}{\mathbf{I}_z}\right) & 0\end{bmatrix} \tag{13}$$

$$\mathbf{B}=\begin{bmatrix}0 & -\frac{1}{I_y} & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & -\frac{1}{I_x} & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{I_z}\end{bmatrix}^T \tag{14}$$

$$\mathbf{C}=\begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\end{bmatrix} \tag{15}$$

3. SPACECTAFT ATTITUDE DETERMINATION AND ESTIMATION

3.1 $\boldsymbol{\alpha\beta}$ *Filter*

This section presents the algorithmic description of the filter employed in our study. Specifically, we utilize a simple filter that has been widely recognized as a valuable tool for estimating the attitude and angular velocity of moving objects. The design of this filter is provided below.

The structure of the $\alpha\beta$ filter is described as:

$$\hat{\mathbf{X}}_{\mathbf{k}}^{-}=\mathbf{F}\hat{\mathbf{X}}_{\mathbf{k}-1}^{+} \tag{16}$$

$$\hat{\mathbf{X}}_{\mathbf{k}}^{+} = \hat{\mathbf{X}}_{\mathbf{k}}^{-} + \mathbf{K}\left(\mathbf{Z}_{\mathbf{k}} - \hat{\mathbf{Z}}_{\mathbf{k}}\right) \tag{17}$$

Where,
$\mathbf{F}$ is the transition matrix;
$\hat{\mathbf{X}}_{\mathbf{k}}^{-}$ and $\hat{\mathbf{X}}_{\mathbf{k}}^{+}$ are respectively, the predicted and the estimated state vectors;
$\mathbf{Z}_{\mathbf{k}}$ is the measurement vector;
$\hat{\mathbf{Z}}_{\mathbf{k}}$ is the predicted measurement vector, defined as,

$$\hat{\mathbf{Z}}_{\mathbf{k}} = \mathbf{C}\hat{\mathbf{X}}_{\mathbf{k}}^{-} \tag{18}$$

$\mathbf{C}$ is the measurement matrix, given by eq (15).
$\mathbf{K_0}$ is the gain of the $\alpha\beta$ filter, it is given by:

$$\mathbf{K_0} = \begin{bmatrix} \alpha_\varphi & \frac{\beta_\varphi}{T} & 0 & 0 & 0 & 0 \\ 0 & 0 & \alpha_\theta & \frac{\beta_\theta}{T} & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_\psi & \frac{\beta_\psi}{T} \end{bmatrix} \tag{19}$$

Where, T is the sampling time period and α and β are the filter gains.
The effectiveness of the filter is dependent upon the selection of its parameters, which are denoted as α and β. Determining the optimal values for these parameters involves striking a balance between the tracking rapidity and the noise reduction capability. The initial optimal relationship between these two coefficients was established by Benedict and Bordner in (Benedict and Bordner,1962).

$$\beta = \frac{\alpha^2}{2-\alpha} \tag{20}$$

However, the best choice of the optimal α remained unknown. To solve this problem, a new parameter called the tracking index was introduced by (Kalata, 1984). This parameter is defined as follows:

$$\lambda = \frac{\sigma_v}{\sigma_w} T^2 \tag{21}$$

Where, σ_v and σ_w are respectively the standard deviations of the system noise and measurement noise.
The method of computing the parameters α and β using the tracking index is summarized in (Bar-Shalom and Fortmann, 1988; Bar-Shalom, 1993) as,

$$\alpha = -\frac{1}{8}\left(\lambda^2 + 8\lambda - (\lambda+4)\sqrt{\lambda^2+8\lambda}\right) \tag{22}$$

$$\beta = \frac{1}{4}\left(\lambda^2 + 4\lambda - \lambda\sqrt{\lambda^2+8\lambda}\right) \tag{23}$$

The stability region of the parameters α and β can be described as,

$$0 \langle \alpha \langle 1 \tag{24}$$

$$0 \langle \beta \langle 4 - 2\alpha \tag{25}$$

3.2 TRIAD Algorithm

Shuster and Oh (Shuster and Oh,1981) developed the TRIAD method, which is a deterministic approach. It involves the creation of two triad vectors based on two pairs of vector measurements: two measured in the orbital reference frame noted $\mathbf{v_1}$ and $\mathbf{v_2}$, and two in the body reference frame $\mathbf{w_1}$ and $\mathbf{w_2}$. The measured noises of $\mathbf{w_1}$ and $\mathbf{w_2}$ are denoted as n_1 and n_2, respectively. The procedure can be summarized as follows, as described in (Itzhack and al,1996):

$$\mathbf{w}_i = \mathbf{A}\,\mathbf{v}_i + \mathbf{n}_i \tag{26}$$

where i=1, 2, and $\mathbf{A}$ is the true attitude matrix.
To implement the TRIAD method, it is necessary to calculate the following column matrices in body coordinates:

$$\mathbf{r}_1 = \mathbf{w}_1/|\mathbf{w}_1| \tag{27.a}$$
$$\mathbf{r}_2 = (\mathbf{r}_1 \times \mathbf{w}_2)/|\mathbf{r}_1 \times \mathbf{w}_2| \tag{27.b}$$
$$\mathbf{r}_3 = \mathbf{r}_1 \times \mathbf{r}_2 \tag{27.c}$$

Similarly, the corresponding column matrices in the reference system are as follows:

$$\mathbf{s}_1 = \mathbf{v}_1/|\mathbf{v}_1| \tag{28.a}$$
$$\mathbf{s}_2 = (\mathbf{s}_1 \times \mathbf{v}_2)/|\mathbf{s}_1 \times \mathbf{v}_2| \tag{28.b}$$
$$\mathbf{s}_3 = \mathbf{s}_1 \times \mathbf{s}_2 \tag{28.c}$$

In the final step of the TRIAD method, the attitude matrix is computed as follows:

$$\mathbf{A} = \mathbf{r}_1.\mathbf{s}_1^T + \mathbf{r}_2.\mathbf{s}_2^T + \mathbf{r}_3.\mathbf{s}_3^T \tag{29}$$

where T denotes the transpose.

4. IN-ORBIT RESULTS

To illustrate the performance of the configuration $\alpha\beta$ filter and TRIAD, we simulate the proposed configuration using real sensors data from the Alsat-1. The satellite's characteristics of Alsat-1 are given in Table 1.

Table 1. Alsat-1's characteristics

Parameter	Value
Mission	Imaging the earth
Moment of inertia [kg.m^2]	$\begin{bmatrix} 152.9 & 0 & 0 \\ -0.25 & 152.5 & 0.0005 \\ 0.1 & 0 & 4.91 \end{bmatrix}$
Orbit altitude [km]	686
Inclination [deg]	98
Attitude control type	Nadir attitude pointing control

Firstly, we present the real attitude and measurements obtained from the attitude sensors installed on Alsat-1.

The in-orbit attitude of Alsat-1 is depicted in Figure 1, and it has been calculated using small Euler angles through the utilization of the Extended Kalman Filter (EKF) algorithm, which has been integrated into Alsat-1.

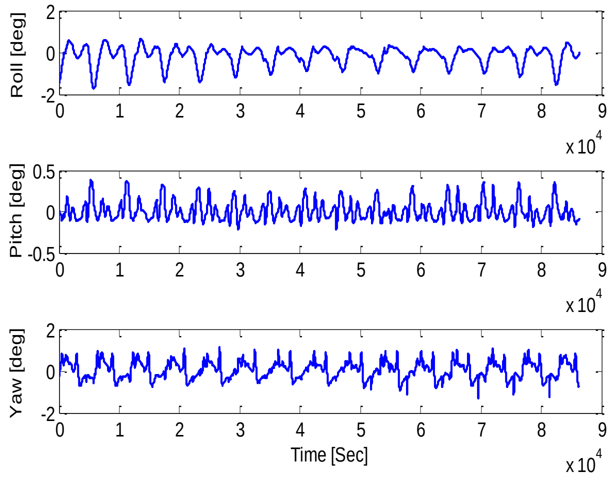

Figure 1. In-Orbit Alsat-1 attitude.

In order to determine the attitude of the satellite shown in Figure 1, a combination of two sensors - the magnetometer and sun sensor - is employed. A detailed breakdown of the specifications for these sensors is provided in Table 2.

Table 2. Sensor specifications (Alsat-1 project doc, 2003).

	Magnetometer	Sun Sensor
Quantity	2	4
Range	$\pm 60\mu$Tesla	± 50deg (Az/El)
Resolution	$\langle 0.5$ deg/sec	$\langle 0.25$ deg
Mass (Kg)	0.295	0.300
Size (mm)	$130 \times 90 \times 36$	$90 \times 107 \times 35$
Power	14mA@12V 8mA@-12V	3mA@12V 110μA@-12V
Thermal characteristics	-50^{o}C to +80^{o}C	-50^{o}C to +80^{o}C

Figure 1 and Figure 2 present the actual measurements obtained from the sun sensor and magnetometer, respectively.

The real flight data presented in figures 1 to 3 were collected in 06th January 2005.

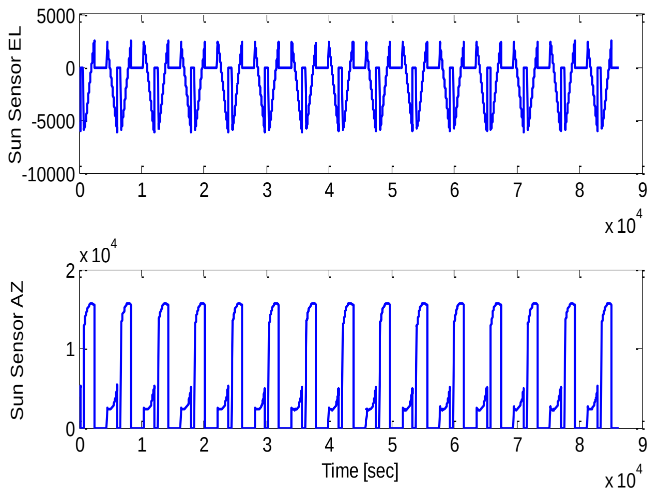

Figure 2. Real measurement provided by sun sensor.

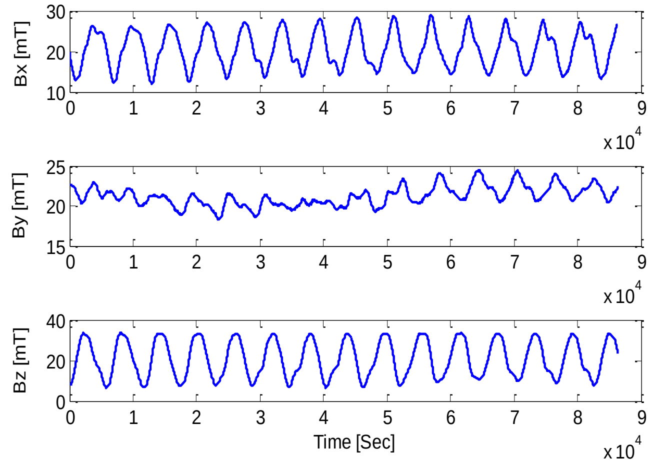

Figure 3. Real measurement provided by magnetometer.

To assess and verify the effectiveness of the designed configuration, a comparative analysis is conducted between the estimated results and the actual flight data of Alsat-1. The comparison between the estimated Euler angles obtained from the designed configuration and the real Euler angle measurements provided by the attitude sensor during the Alsat-1 mission is illustrated in Figure 4and Figure 5.

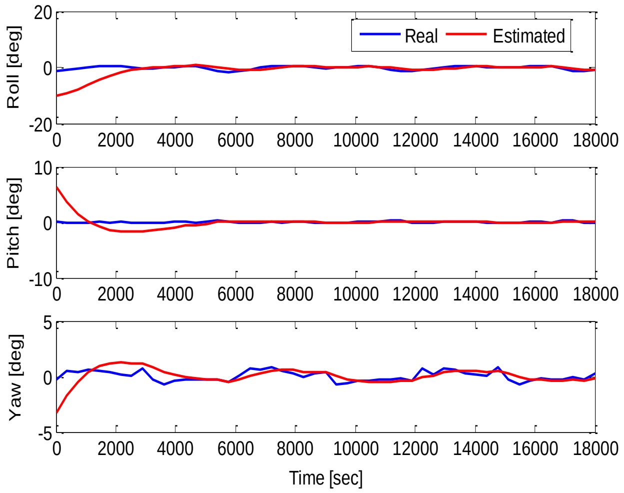

Figure 4. Real and estimated attitude.

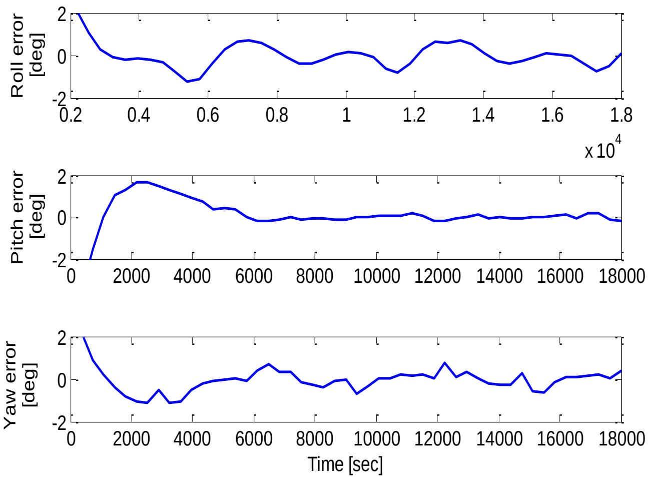

Figure 5. Errors of the estimated attitude.

Table 2. Performance evaluation of the $\alpha\beta$ filter.

	RMS error [deg]	Convergence time [sec]	Computation time for PC [sec]	Computation time for OBC 750 [sec]	Percentage of computation time [%]
αβ filter with TRIAD	Roll Pitch Yaw $\begin{bmatrix}0.2706\\0.0504\\0.3422\end{bmatrix}$ 0.4028	4000	0.3900	8.5660	52.67

The combined configuration of the $\alpha\beta$ filter and TRIAD algorithms has been found to produce results that closely resemble the actual results of Alsat-1, with an absolute error of less than one degree, as demonstrated in Figure 5 and Table 2. One of the key reasons for selecting this configuration is that both the TRIAD and $\alpha\beta$ filter algorithms are simple and easy to implement in satellite projects, making them ideal due to their exceptional characteristics. By dividing the sensor load between the sun sensor and magnetometer to the TRIAD algorithm, power concerns can be addressed. Therefore, if one sensor fails to operate, the other sensor can still transfer attitude data effectively. The perfect integration of TRIAD with the $\alpha\beta$ filter algorithm, which is the fastest algorithm with a lower computational load, leads to swift data transfer and efficient sensor handling.

5. CONCLUSION

This paper introduces a novel configuration for estimating spacecraft attitude that provides high accuracy while simultaneously reducing computational load. This configuration is based on combining the filter with the TRIAD algorithm. the proposed configuration was simulated using real sensor data from the first Algerian satellite, Alsat-1. The results revealed that the proposed configuration exhibited acceptable performance and reduced computational requirements. The simulation outcomes were also similar to the actual results obtained from Alsat-1.

REFERENCES

Alsat-1 project documentation delivred by SSTL to CNTS under the Know How Transfer Program (December 2003)

Arasaratnam, I., Haykin, S., Hur, TR93 (October 2010). Cubature Kalman filtering for continuous-discrete systems: theory and simulations IEEE Transactions on Signal Processing. 58(10), 4977

Bar-Shalom, Y., Fortmann, T. E(1988). Tracking and Data Association. Academic Press

Bar-Shalom, Y., Li, X. R (1993). Estimation and Tracking; Principles, Techniques, and Software. Boston, MA: Artech House

Benedict, T.R., Bordner, G.W (1962). Synthesis of an optimal set of radar track-while-scan smoothing equations. IRE Transaction on Automatic Control. 7(8), 27–32

Crassidis, J.L., Markley, F.L., Cheng, Y (2007). Survey of nonlinear attitude estimation methods. The journal of guidance, control and dynamics. 30(1), 12-28

Donghe, Y., Jinsong, X. (2009) Face tracking based on camshift algorithm and motion prediction. International Work shop on Intelligent Systems and Applications. 1–4

Hashida, Y (2004). ADCS Design for Future UoSAT Standard Platform. Surrey Space Center, Guilfort, UK, Chapter 2, SSTL International Report, 19-20

Itzhack Y. Bar-Itzhack, Richard R. Harman (1996). OptimiZED Triad Algorithm for Attitude Determination. journal of Guidance Control and Dynamics 20 (1), 208-211

Jazwinski, A. (1970). Stochastic Processes and Filtering Theory. New York: Academic Press

Kalata, P.R (1984). The tracking index a generalized parameter for αβ and αβγ target trackers. IEEE Transactions on Aerospace and Electronic Systems. AES-20, 174–182

Kalman, R. E (1960). A New Approach to Linear Filtering and Prediction Problems Trans. ASME-Journal of Basic Engineering. vol. 82, 34-35

Lefferts, E.J., Markley, F.L., Shuster, M.D (1982). Kalman filtering for spacecraft attitude estimation. The journal of guidance, control and dynamics. 5(5), 417-429

Markley, F.L., Crassidis, J.L., Shuster, M.D (2005). Nonlinear attitude filtring methods. AIAA Guidance, Navigation, and Control conference and Exhibit. San Francisco

Markley, F.L (2003). Attitude error representations for Kalman filtering.The journal of guidance, control and dynamics. 26(2), 311-317

Meche, A., Dahmani, M., Keche, M., Ouamri, A (2013). A simplified $\alpha\beta$ based Gaussian sum filter. International Journal of Electronics and Communications (AEÜ). 67, 313–318

Mekky, T., A H A (2013). comparative study of spacecraft attitude determination and estimation algorithms (a cost-benefit approach) Aerospace Science and Technology. (Elsevier) vol 26, 211-215

Qiu, Z., Qian, H., Wang, G (2018). Adaptive robust cubature Kalman filtering for satellite attitude estimation. Chinese Journal of Aeronautics, 31(4), 806-819

Quang, M. L., Raymond V. W., Walter, G., Douglas C. F (1996). Development of an alpha-beta filter based orbit determination system. AIAA Meeting Papers on Disc. 287-296

Sharma, S., Deshpande, S., Sivalingam, K.M (2011). Alpha-beta filter based target tracking in clustered wireless sensor networks. Third International Conference on Communication Systems and Networks. 1–4

Shuster M. D. and S. D. Oh (Jan 1981). Three axis attitude determination from vector observations. J. Guid. Control, 4(1), 70–77

Si Mohammed, M.A., Bellar, A., Adnane, A., Boussadia, H (2016). Performance Analysis of Attitude Determination and Estimation Algorithms Applied to Low Earth Orbit Satellites. UKACC 11th International Conference on Control (CONTROL), Belfast

Soken, H. E., Hajiyev, C., Sakai, S (2014). Robust Kalman fltering for small satellite attitude estimation in the presence of measurement faults. European Journal of Control. 20, 64-72

Soken, H.E., Hajiyev, C (2012) . Robust Kalman filtering with single and multiple scale factors for small satellite attitude estimation. Advances in Estimation, Navigation, and Spacecraft Control. 391-411

Trag, H.C., Chen, J.C (2009). Rear-end collision warning system on account of a rear-end monitoring camera. In: IEEE Intelligent Vehicles Symposium. p. 913–7

Wertz, J. R (1991). Space Mission Analysisd Design, Kluwer Academic Publishers, Dordrecht-Boston-London, Space Technology Library

Zamri, M. and all (2016). Review on attitude estimation algorithm of attitude determination system ARPN journal of engineering and applied sciences. vol 11, 4455-4460