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USING ALPHA – BETA FILTRATION FOR ROBUSTNESS IMPROVEMENT OF A QUADROCOPTER POSITIONING SYSTEM

Quadrocopter is an unmanned aerial vehicle (UAV) platform. The position of the robot is determined based on readings from an accelerometer and a gyroscope, but the measurement signals contain broadband noise. This article describes a solution for filtering out the noise based on an Alpha – beta filter. It also presents the methodology of designing and implementing such a filter for noise cancellation in measurement signals from accelerometer and gyroscope. The computational complexity of the Alpha – beta filter is similar to a second order low pass filter, but there are no noticeable time delays and filtration gives similar results to that of a Kalman filter. The described filter was designed and implemented in a real vehicle, tested and validated.

KEYWORDS: signal processing, discrete filter, robotics

1. INTRODUCTION

A quadrocopter has four motors with propellers, connected in pairs spinning in opposite directions. The position of the robot is controlled by an embedded control system, but the reference values are defined by operator using wireless communication. To change the location of the quadrocopter, the angular velocity of appropriate rotors has to be changed. Quadrocopters are mainly used as radio controlled toys [1], camera platforms or research tools [2].

All solutions presented in this paper were tested on a real object, which was described in [3]. This robots' actual position is calculated based on readings from a 3-axis accelerometer and a 2-axis gyroscope. The measurement signal contain noises and proper noise cancellation is required for the correct working of the control system.

The selection of the filtration method is an important stage of the design of a quadrocopter control system. This paper presents an Alpha – beta filter design and an analysis of its usefulness for the improvement of a quadrocopter positioning control system. This solution is characterized by simplicity and low

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computational complexity, which allows for easy real-time implementation and low energy consumption without compromising performance.

2. SURVEY OF RELATED WORKS

The most popular method of noise cancellation in measurement signals for a quadrocopter control system is Kalman [4][5] or Extended Kalman filtration [6][7]. This method meets the requirements of most of the control systems. Time delays are minimal and noise cancelation satisfies the desired accuracy.

A different, widely used noise cancellation algorithm is the MARG filtration [8]. This algorithm is based on quaternions – a number system that extends the complex numbers.

3. ALPHA – BETA FILTRATION

We propose to use Alpha – beta filtration for its simplicity. This method, much like Kalman filtration, estimates values based on previous estimated values and current measurements [9]. Alpha – beta filtration does not introduce time delays. It does not require a mathematical model of the robot, as it is approximated by a second order model.

The first step of designing an Alpha – beta filter for noise cancellation was the construction of a mathematical model of the robot in Matlab. For that purpose, measurements had to be made on the actual quadrocopter.

3.1. Modeling

Measurements are made in the X, Y and Z axis. X and Y are in the same plane as the robot frame, and Z is perpendicular to this plane. The coordinate system origin is the same as the center of the robot. Control system in X axis is separate from the Y axis. Control is determined separately for the X and Y, so considerations will be carried out only for one axis.

Position of the robot in the X axis is calculated on the basis of readings from the accelerometer in axis X and Z. This method is presented on Fig. 1.

If the forces acting on the object are balanced, the accelerometer measures only gravity.

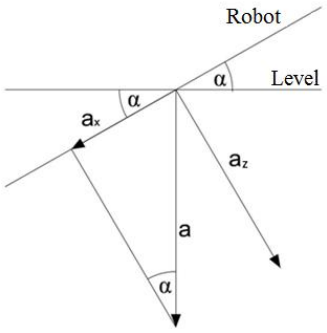

Fig. 1. Calculating position of the robot in axis X

The angle α between the robot and the level is calculated on the basis of acceleration a_x in X axis, acceleration a_z in Z axis and acceleration due to gravity a, which is equal to 1 g, in accordance with (1).

$$\alpha = \arctan\frac{a_x}{a_z} \tag{1}$$

Next, a correction of the calculated position α is computed using gyroscope measurements, in accordance with (2).

$$x_m = k(\alpha + \omega \cdot T) + (1-k)\alpha \tag{2}$$

Where x_m is the measured position of robot in X axis, k is a parameter which values are higher than 0 and lower than 1 and T is time between calculations. The k parameter selection is described in [3].

The next step is noise cancellation using Alpha – beta filtration [10].

$$\begin{aligned} x_s(k) &= x_p(k) + \alpha_f\left[x_m(k) - x_p(k)\right] \\ V_s(k) &= V_p(k-1) + \frac{\beta_f}{T}\left[x_m(k) - x_p(k)\right] \\ x_p(k+1) &= x_s(k) + TV_s(k) \\ V_p(k+1) &= V_s(k) \end{aligned} \tag{3}$$

Where $x_s(k)$ is the smoothed position, $V_s(k)$ is the smoothed velocity, $V_p(k)$ is the predicted velocity, $x_p(k)$ is the predicted position, $x_m(k)$ is the measured position and α_f, β_f are parameters of the Alpha – beta filter. The result of the filtration is the predicted position for time $k+1$, $x_p(k+1)$. Parameters are selected on the basis of observations of the result of the filtration.

3.2. Implementation

The Alpha – beta filtration was first prepared in Matlab. After that, it was implemented in a real quadrocopter.

The first step was to prepare the measurement signals for filtration. To be able to evaluate the filtration algorithm we need the measurement signal free of any noise. To solve this problem a noise model was prepared based on the noise extracted from the signal measured in a real object. The spectrum of the extracted noise signal has been presented on figure 2.

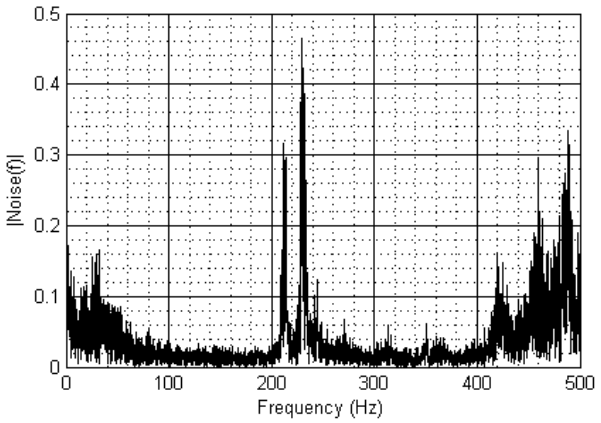

Fig. 2. Spectrum of noise signal

The reference signal, shown in fig.3, was prepared based on a signal obtained from the robot prototype, so it has the same maximal and minimal values, and similar variability.

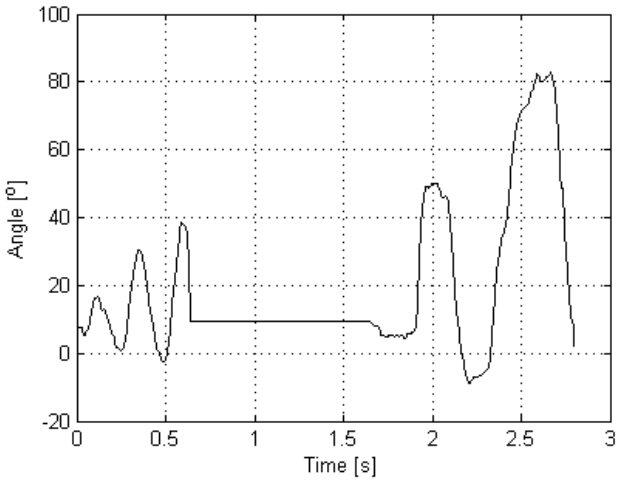

Fig. 3. Reference signal

All measurement signals were sampled with frequency of 1 kHz.

After preparing the model of the signal and noise, the filtration algorithm (3) was implemented in Matlab. Next, the values of filter parameters α_f and β_f were determined. The parameters should be constrained as follows:

$$\begin{aligned} 0 < \alpha_f < 1 \\ 0 < \beta_f \leq 2 \\ 0 < 4 - 2\alpha_f - \beta_f \end{aligned} \tag{4}$$

Parameters have been chosen experimentally. A high value of parameter α_f will cause the output signal to be similar to the input signal and any distortions will be suppressed only by a small degree. A low value will cause the distortions to be strongly suppressed, but the output signal rises slowly. Parameter β_f is correlated with the second derivative of the input signal and its value determines the time delay. This parameter is crucial for the stability of the filtration. A value too high will cause the system to be unstable.

The values have been established as follows: $\alpha_f = 0.19$ and $\beta_f = 0.09$. Figures 4 and 5 present the results of filtration.

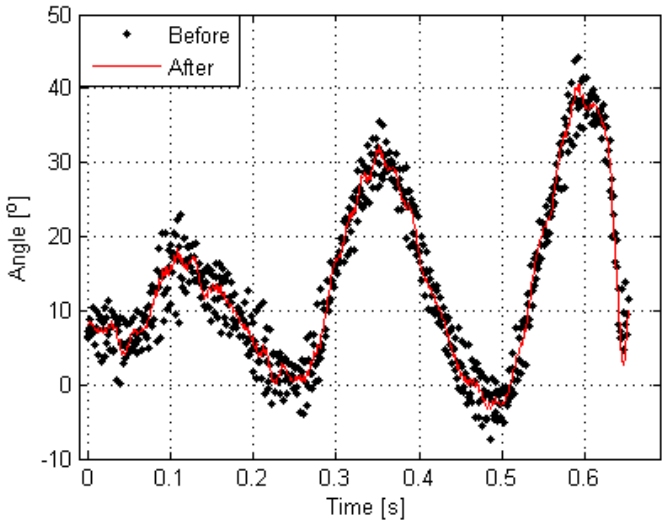

Fig. 4. Results of filtration with parameters: $\alpha_f = 0.19$, $\beta_f = 0.09$

The signal before filtration contains a lot of noise. The output signal is similar to the reference signal. There are noticeable signal overshoots. As we can see on figure 5 there is no time delay between the reference signal and the filtered signal, which is crucial in preparing a proper control system.

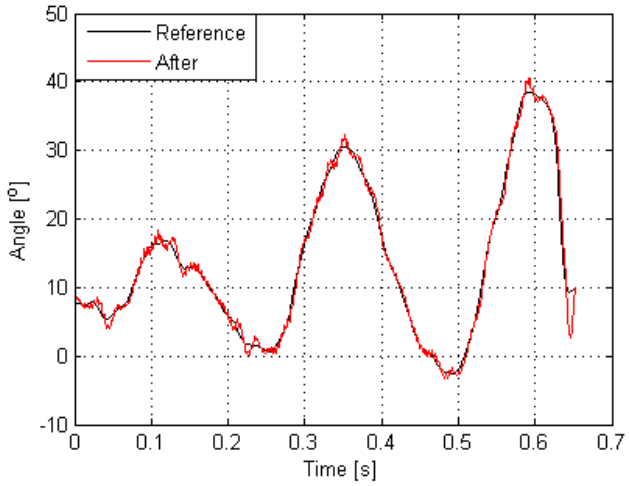

Fig. 5. Comparison of reference signal and signal after filtration

The maximum relative error of filtration, relative to the reference signal, is equal to 3% . This value was calculated taking into account the whole signal presented in figure 3.

Alpha – beta filtration has similar computational complexity as a low pas filter implemented earlier in the robot and described in [3]. Figure 6 presents the comparison of Alpha – beta filtration and low pas finite impulse response filter.

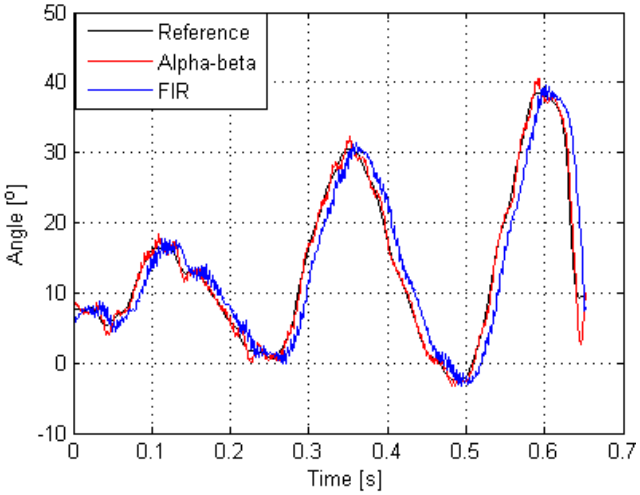

Fig. 6. Comparison of Alpha – beta filter and FIR filter

3.3. Verification

After implementing the algorithm in Matlab, the designed Alpha - beta filter has been implemented and tested on a real object. Filtering parameters calculated while testing the algorithm in Matlab did not require adjustments, and the data collected from the real object was similar to that calculated using the model.

Changing the filtration algorithm to the Alpha - beta allowed for better positioning of the robot, compared to the earlier version [3]. The behavior of the robot is easier to predict for the operator because of the absence of delays in the measurement signals.

4. CONCLUSION

The Alpha – beta filtration concept and implementation was presented. The results obtained confirm the assumptions: Alpha – beta filtration does not introduce time delays present in typical low pass filters. The presented method does not require a mathematical model of the robot. The parameters of the filter are constant as opposed to the Kalman filter, where kalman gain is calculated in every step of algorithm. This difference is what makes this filtration solution less complex than a Kalman filter. The use of an Alpha – beta filter allows for a significant reduction of computational complexity at an adequate accuracy.

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WYKORZYSTANIE FILTRU ALFA - BETA DO POPRAWIENIA KRZEPKOŚCI SYSTEMU POZYCJONOWANIA ROBOTA TYPU QUADROCOTER

Quadrocopter jest bezzałogową platformą (ang. Unmanned Aerial Vehicle). Pozycja robota jest wyznaczana w oparciu o odczyty z akcelerometru oraz żyroskopu, ale sygnały pomiarowe zawierają szum o szerokim spektrum.

Artykuł prezentuje wyniki implementacji algorytmu filtracji Alfa – beta w systemie kontrolnym robota typu quadrocoter. Przedstawiono również metodykę projektowania i wdrażania filtru dla sygnałów pomiarowych z akcelerometru i żyroskopu

Złożoność obliczeniowa filtru alfa - beta jest podobna do filtru dolnoprzepustowego drugiego rzędu, jednak nie występują zauważalne opóźnienia czasowe, a filtracja daje podobne wyniki do tych uzyskanych z filtru Kalmana.

Opisany filtr został zaprojektowany w środowisku Matlab i wdrożony w rzeczywistym pojeździe.