The Use of Kalman Filter in Control The PanTilt Two-Axis Robot With Wearable System

Temel Sonmezocak

Abstract—**Today, the use of micro electromechanical system (MEMS)-based control-based unmanned aerial vehicles is becoming widespread. The control of the vehicles during use can be done with joystick control connected to a fixed monitor in order to monitor the environment during flight. This situation brings with it some limitations in the activities of users to monitor the environment or direct the vehicle. However, it is important that the systems used for the vehicles control are used extremely sensitively and effectively. In this study, a 2-axis robotic pan-tilt system based on human-machine interaction and a wearable MEMS gyroscope-based headband is designed for remote control of unmanned aerial vehicles by creating an augmented reality perception on users. Therefore, it brings the perception of reality with the head movements of the users and the convenience of watching the environment during the flight. In addition, the signals produced by MEMS, the vibrations caused by electrical noise in the motors due to human interaction and environmental factors, are effectively eliminated with the Kalman filter. In this way, the images transmitted to the pilot become smoother. Therefore, it is cost-effective as it eliminates the need for additional hardware filtering structures.**

Index Terms—**Accelerometer, Kalman filter, micro-electromechanical, servo control, signal processing, wearable systems.**

I. Introduction

MICROELECTROMECHANICAL SYSTEM (MEMS) gyroscope and accelerometers are used in today's systems as a highly developed structure in the measurement and control of motion acceleration, vibration and motor rotation angles [1-4]. In recent studies, filtering methods for the Kalman model can be used in the stabilization of MEMS accelerometer / gyroscope type systems, servo motor systems and in filtering the resulting vibrations. In the studies, balancing robots are designed to stabilize devices such as video recorders, sports cameras or smart phones during movement. In this way, the position of the camera is stabilized during movement [5,6]. For this type of systems, a new Orientation Axes Crossover Processing (OACP) algorithm based on vibration optimization by measuring vibrations with a MEMS accelerometer is developed to eliminate vibrations on the pan-tilt system. Kalman and low-pass filters are also used [7]. Similarly, for the most effective estimation of angular acceleration signals with 3-axis gyroscope, extended Kalman filter (EKF) and master-slave Kalman filter algorithm created with inverse ϕ-algorithm are used [8]. These studies, the roughness of the land, wind, etc. vibration-induced noises are prevented by using MEMS systems mounted on a pan-tilt platform. This is very important for the control of camera rotation angles in the pan-tilt system.

Unlike these studies, this study focuses on the effective use of wearable First Person View (FPV) / virtual reality (VR) type monitor glasses of a pan-tilt system on a unmanned aerial vehicle (UAV) based on human interaction. In addition, high-frequency noises caused by the sudden head position movement of the human body created by a MEMS-based 2-axis gyroscope sensor positioned on the human body, as well as electromagnetic-based noises caused by environmental factors, are effectively filtered using the Kalman filter without the need for an external hardware filtering. Therefore, the vibrations of the servo motors in the X and Y axis in the pan-tilt system are effectively eliminated. In this study, a headband wearable wireless headband is designed. With the pan-tilt camera system mounted on the UAVs, an augmented reality perception is created for the pilot by directing the wireless camera with the head movements of the pilot during the flight. This designed system does not require additional active filter hardware resources. Considering the wireless communication, the effectiveness of the Kalman filter in terms of speed performance due to human interaction only with the process noise parameter is observed in the experiments.

II. Materials and Methods

A. Signal Acquisition

In this study, the X and Y axes of the MPU6050 system were used together as a MEMS accelerometer/gyroscope. MPU6050 can be used both as a 3-axis gyroscope for angular velocity measurement and as an accelerometer for linear acceleration measurement [9]. This chip has a 16bit A/D analog converter [10]. The angles of the MEMS system on the wearable platform are ρ for the X axis (Roll) and φ for the Y axis (Pitch), Eq. It can be determined in Eq. (1) and (2) [6].

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$$\rho = \tan^{-1}\left(\frac{a_x}{\sqrt{a_y^{\,2} + a_z^{\,2}}}\right) \tag{1}$$

$$\varphi = \tan^{-1}\left(\frac{a_y}{\sqrt{a_x^{\,2} + a_z^{\,2}}}\right) \tag{2}$$

where, a_x, a_y and a_z, are the X, Y and Z axis components of the gravitational acceleration. In addition, the angular rotation speed of the axes (ω) is proportional to the capacitance changes of the gyro. Therefore, MEMS accelerometer/gyro systems work according to the capacitive effect [11,12]. The change of ω caused by this effect is expressed in Eq. (3).

$$\omega = \frac{dc}{dt} \tag{3}$$

where ω is proportional to velocity of slew change capacity according to time t. Therefore, when we rearrange all this information, the time-dependent changes of the angles in the X and Y axes are calculated as shown in Eq. (4) and Eq. (5).

$$p(t) = p(0) + \int_0^t \omega_x(\tau)d\tau \tag{4}$$

$$\varphi(t) = \varphi(0) + \int_0^t \omega_y(\tau)d\tau \tag{5}$$

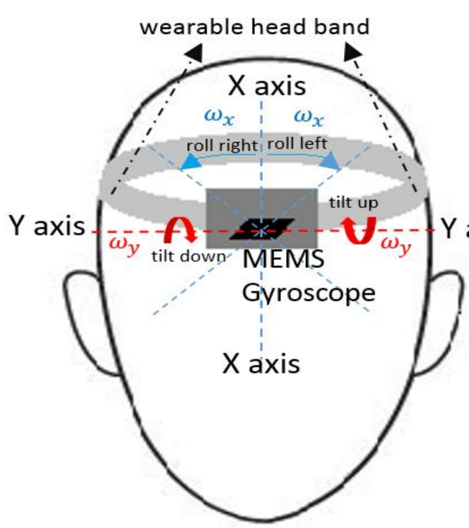

Fig.1. MEMS axes positioned on the wearable head

Fig. 1 shows the positioning of the MEMS accelerometer axes placed on the wearable headband. The data obtained from both sensors creates involuntary noises due to their sudden changes. These noises cause sudden changes or vibrations in servo motors.

In this study, two 8-bit 20MHz Atmega328 microcontrollers are used in both the receiver and transmitter circuit structure for the processing of angular data obtained by MEMS. Data from the MEMS gyroscope sensor is sampled over the Inter-Integrated Circuit (I2C) serial port for 77 samples in 1 second (sample frequency 77Hz). NRF24L01 2.4 GHz transceiver module is used directly to transmit these sampled signals [13]. In this way, signals are transmitted to the pan-tilt system wirelessly. However, the data sent to the pan-tilt system consists of raw noisy data. These transmitted data are received by the wireless NRF24L01 2.4 GHz transceiver and converted into pulse with modulation (PWM) signals before being transmitted to the pan-tilt system in the receiving part. These translated signals are transmitted to the 8-bit 20MHz Atmega328 microcontroller built in the receiver part with the serial peripheral interface (SPI) protocol for processing by converting the signals into angle information in digital environment. Noise is also raw signals, as these received signals are carried by MEMS with the sudden change of body movements and over long distances. Therefore, the filtering of these signals is done on the receiving system. The Kalman model was used to filter these signals. In this filter, the process noise w_k parameter is used effectively in the filtering of the signals in this study before they are transmitted to the servo motors in the pan-tilt system in the receiving part. In addition, in terms of the performance of the system, the noisy signals are digitized raw and filtered with different w_k parameters and transferred to the PC environment for real-time analysis. MATLAB software was used for analysis. The experimental setups and block diagrams of these studies are shown in Fig. 2 and Fig. 3.

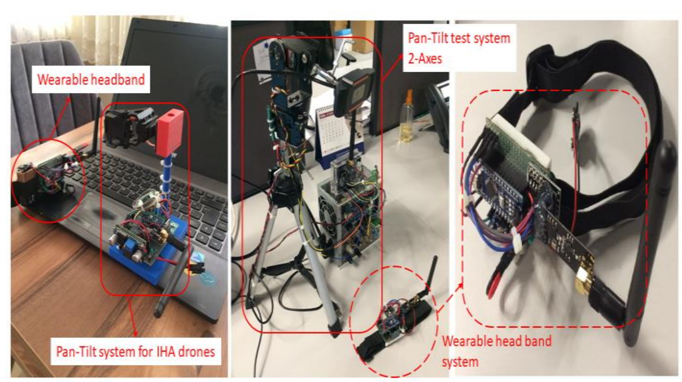

Fig.2. Experimental setups of the system

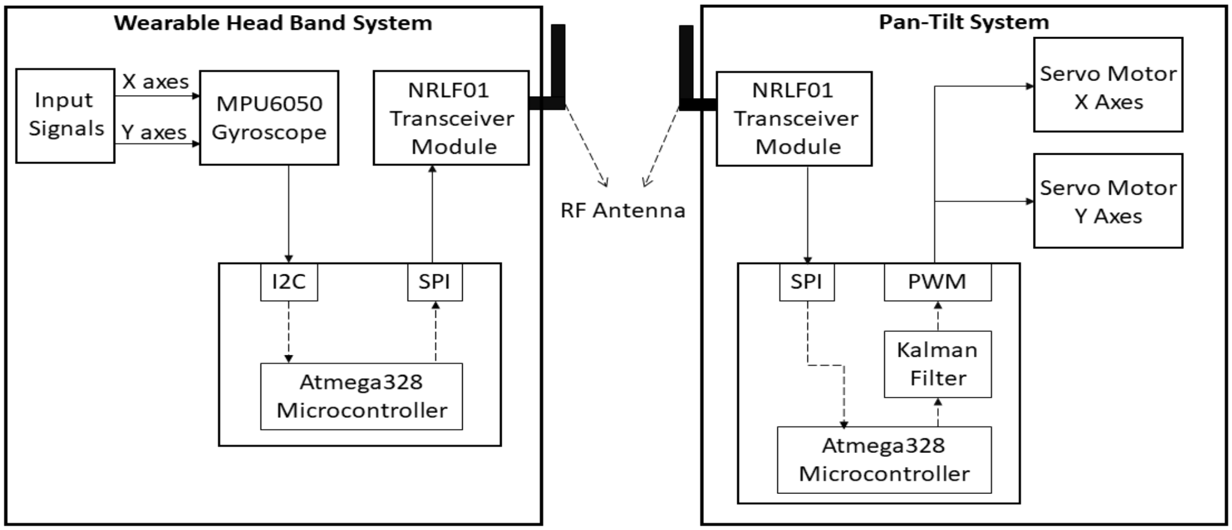

Fig.3. Block diagram of the designed system

B. Kalman Filter

Kalman filter (KF) was introduced by Rudolf Kalman. This dynamic model is being used in position tracking systems of space vehicles, robotic control systems, and biomedical signal processing systems [14,15]. In this method, the equation of a nonlinear signal discretized at each moment *k* and the measurement equation are modeled as in Eq. (6) and Eg. (7).

$$X_k = AX_{k-1} + w_k \tag{6}$$

$$Z_k = HX_k + v_k \tag{7}$$

In these equations, *Xk* is the value of signal *X* at moment index of *k*, Z_k is the measured value of signal *X* at moment index of *k*. w_k and v_k values are respectively process noise and measurement noise of the signal at moment index of *k*. These values are expressed as Q_k and R_k covariance matrices. It is easy to find parameter R_k from here; however, it is not easy to calculate parameter Q_k. Error covariance P_k is calculated from this parameter and is updated in a continuous loop according to the previous error covariance value $\hat{P}_k$ and Kalman gain (K_k) at moment index of *k* in Eq. (9). Updating of the error covariance is expressed in Eq. (10) [6,16].

$$P_k^- = AP_{k-1}^- A^T + Q_k \tag{8}$$

$$Kk = P_k - H^T (HP_k^- H^T + R)^{-1} \tag{9}$$

$$P_k = (1 - K_k H) P_k^- \tag{10}$$

$$\hat{X}_k = \hat{X}_k^- + K_k (Z_k - HX_k^-) \tag{11}$$

The estimated output signal values are updated according to Eq. (11) by updating the covariance values for each moment index of *k* with the predicted error covariance expressed in Eq. (8) and K_k parameter. This updated signal represents the new filtered signal for each moment index of *k*.

III. Experimental Results and Discussions

In this study, the time-dependent changes of the angular values of real-time signals sent to the pan-tilt system, both unfiltered and filtered, are examined comparatively. For this reason, 10 s data is used in the experiments with the user's head up/down movements. In order to test the filter performance in experimental studies, v_k parameters were kept constant in each filtering process, and experiments were made with different w_k parameters.

When the graphs in Fig. 4(a), (b) and (c) are examined separately, the existing noises can be eliminated with different w_k parameters by keeping the v_k values constant. Especially, as seen in the Fig. 4(a) and (b) graphs, filtering can be effective when the w_k parameter takes values between 0.1 and 0.01. In addition, as can be seen in Fig. 4(a), the 0.1 value of w_k, the temporal shift is 0.1 s, which is too small to be felt by the human eye. The angle values of the servo motors in the pan-tilt system remain almost the same, with a maximum deviation of 3 degrees depending on the angle value in the head movements of the user and the sudden change of direction of the head. In field experiments conducted by different people, this situation seems to be suitable for comfortable viewing performance from the camera, especially on external FPV/VR glasses screens of UAV users. On the other hand, with w_k value of 0.001, the noise in the signals is completely eliminated. The time shift in the filtered signals is in the order of 1 s compared to the original signal. Angular amplitude values in servo motors may shift about 40 degrees. This situation prevents the desired control of the pan-tilt system with human head movements.

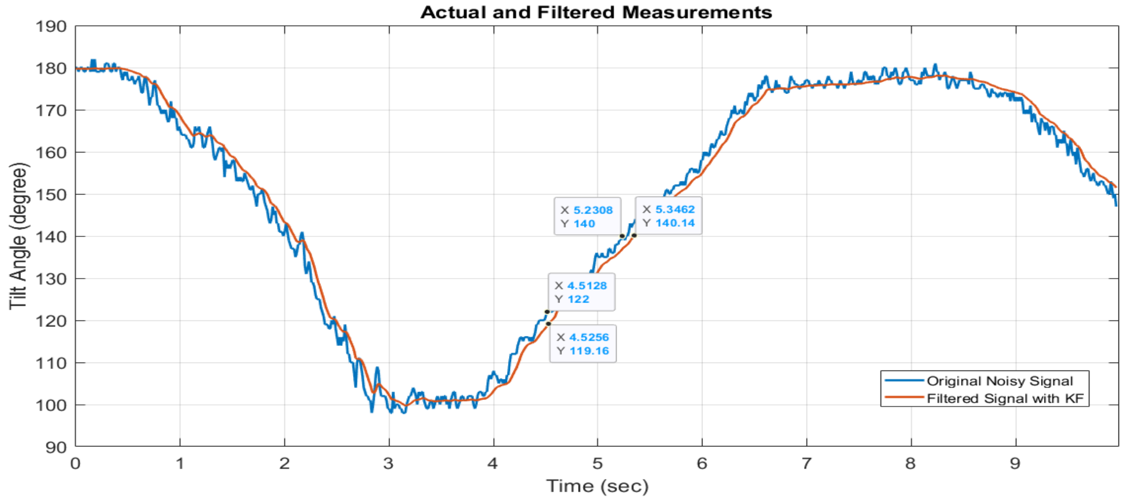

Fig.4(a). Time dependent variation of angular changes of signals filtered with process noise (w_k: *0.1*)

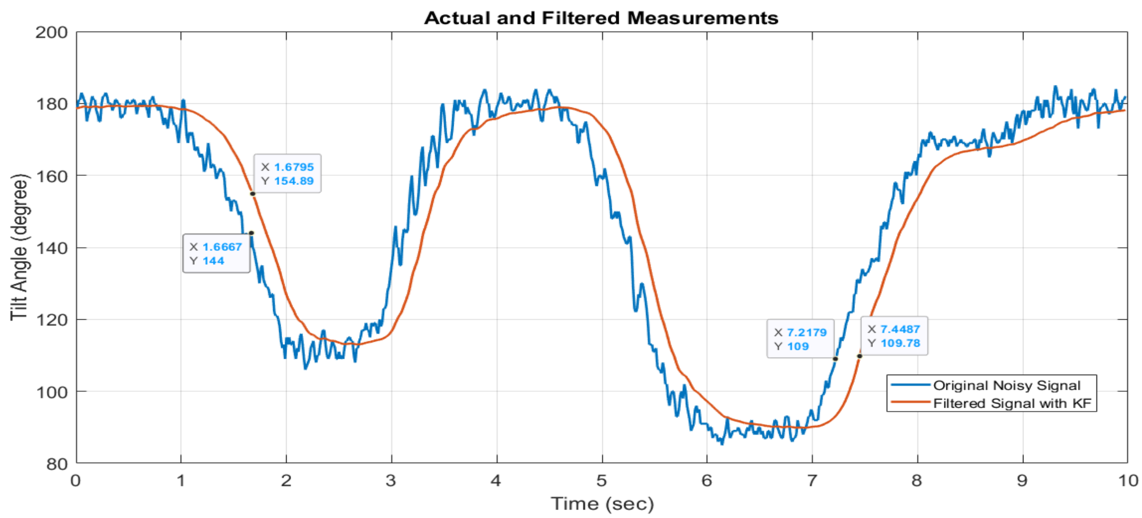

Fig.4(b). Time dependent variation of angular changes of signals filtered with process noise (w_k: *0.01*)

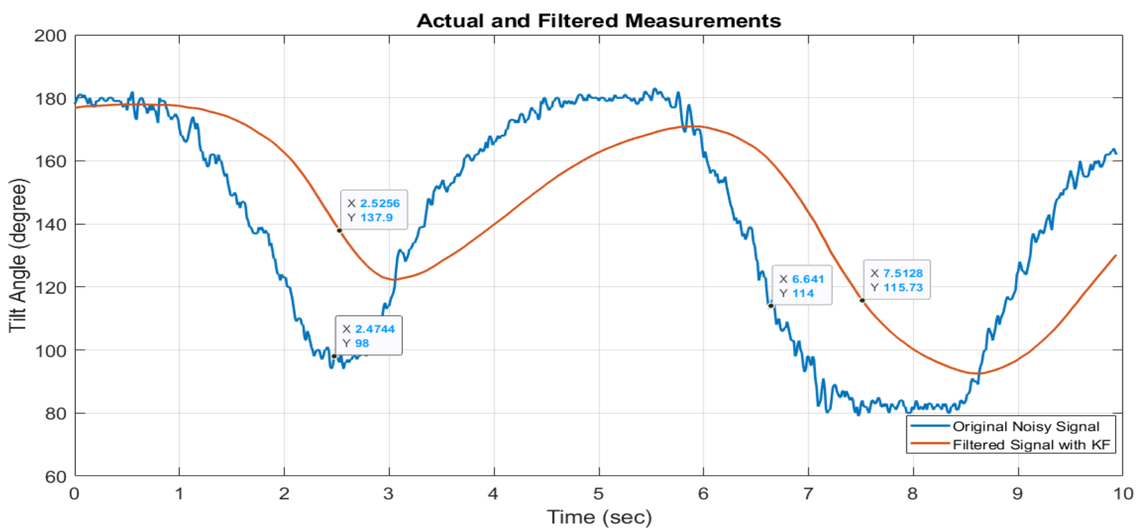

Fig.4(c). Time dependent variation of angular changes of signals filtered with process noise (w_k: *0.001*)

As a result, time delays in the filtered signals and angular deviations in pan-tilt servos occur by decreasing the w_k parameter in software while filtering. On the other hand, by increasing the same parameter, this time the shifts in time are minimal and the angular amplitudes are the minimum deviations. When using this method, process noise parameters are used in the range of 0 to 1. The parameter values used in optimum filtering ranges between 0.1 to 0.01. In this way, there is no need for external hardware filtering structures, but it is a low-cost system, especially for human-interactive remote-control systems connected to FPV/VR wearable glasses systems.

IV. Conclusion

In this study, a headband working with human body interactive control is designed for the effective use of wearable FPV/VR type monitor glasses of a pan-tilt system on the UAV. Noisy signals from MEMS gyroscop detection and environmental factors are effectively filtered based on Kalman filter. In this way, the vibrations created by the electrical signals transmitted to the motors are eliminated. In addition, the effect of the process noise parameter used in filtering on the filtering performance was investigated. By using only this parameter, remote control is provided quickly and without delay, and it is cost-effective since there is no need for an external hardware filter structure.

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BIOGRAPHIES

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