The Application of Series Kalman Filter Based on Measurement Angle

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Abstract—The objective of this research project is to construct an Inertial Measurement Units (IMU), which will design filter for use equation on kalman filter based and use algorithm on MCU. The sensor design, we use low-cost sensor on gyroscope and accelerometer for measuring angle of system. The filter structures of the system, based on kalman filter and use series kalman filter for measurement. This project will get data from experimental results to develop on simulation to illustrate the effectiveness of each filter scheme. Simulation study of kalman filter on different series kalman filter to using on accelerometer.

Keywords—Inertial Measurement Units; Kalman Filter;

1. INTRODUCTION

Modern technology allows the robot to be used widely in the areas of everyday life such as educational, industrial and medical areas. For Example, the iBOT is an electric powered wheelchair that was developed by Dean Kamen and other engineers at DEKA research & development corporation in the 1990s (iBOT) [1], is an example. It can be moved to different places freely and lifted two wheels to self-balancing on the basis of inverted pendulum.

In such a system, which has a sensor to measure the angle to be controled, such as a variable resistor gyroscope, accelerometer and so on. It has been reported that in the conventional, it is difficult to measure precise angle using an accelerometer or gyroscope under some circumstances.

In this research, Kalman filter was invented by Dr. Kalman[2]. It has been used by mathematicians to help in the design of the estimation and apply to the a variety of research.

The car park automation [3], we use kalman filter to approximate the distance to the park from the infrared sensor and ultrasonic sensor, and use equations 1D.

In 2015, They have applied the fuzzy logic and the adaptive Kalman filter to control self-balancing of wheelchair and obtain precise angle measurement of the wheelchair with high dynamics [4].
In this paper we propose a new method to measure precise angle of system by using the kalman filter and series kalman filter. It will be found that the propose method is useful by showing simulation results.

II. HARDWARE DESIGN

In this section, we discuss on the wheelchair design to realize smooth movement for uphill slope, ground level, and ladder.

In order to show the effectiveness of our method, simulations as show in Figs.1-3 are made.

![Fig. 1, The general structure of wheelchair](image)

![Fig. 2, The uphill slope and moving on the Ground level](image)

![Fig. 3, Climbing ladder and Balancing of wheelchair](image)

III. INERTIAL MEASUREMENT UNITS

Inertial Measurement Units (IMU), we design gyroscope and accelerometer to work together and approximate output of angle in low-cost sensor and use gyroscope by LPR503AL LPR510AL LPR550AL, Angular Measurement Rate ±30,±90,±100,±400,500,2000°/sec, Null Accuracy ±1,±2.5°/sec. Power supply at 3.3V. By the estimation of the angular velocity follow form Eq. (1)

$$\omega_{\text{gyro}} = \frac{\text{LSB}_{\text{read}} - \text{LSB}_{\text{zero rotation value}}}{\text{Nominal sensitivity}}$$  \hspace{1cm} (1)

In accelerometer, we used in MMA7361L, Measurement Range ±1.5,±6g, Sensitivity ±800, ±206 mV/g. Power supply at 3.3V. By the estimation of the angular follow form Eq. (2)

$$\theta_{\text{accel}} = \arcsin \left( \frac{\text{LSB}_{\text{read}} - \text{LSB}_{\text{zero rotation value}}}{\text{Nominal sensitivity}} \right)$$  \hspace{1cm} (2)

IV. KALMAN FILTER

The Kalman filter is an algorithm that uses a series of measurements observed over time. We can design discrete-time of kalman filter by $x_k$. $x_k$ is state variable at time. $t_k$ is the needs of time, $t_0, t_1, t_2, \ldots, t_k$ and $k$ is timing of each round of the time step. It follows form Eq. (3)

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1}$$  \hspace{1cm} (3)

We can design state variable 2 Dimension follow form Eq. (4)

$$\begin{bmatrix} \theta_k \\ \omega_k \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & \alpha \end{bmatrix} \begin{bmatrix} \theta_{k-1} \\ \omega_{k-1} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u_{k-1} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} w_{k-1}$$  \hspace{1cm} (4)
Equation (4) is a mathematical model of the system. \( w_{k-1} \) is replica of interference occurring in the system. Has Mean = \( \mu_{w_k} \), by define mean is follow form Eq. (5)

\[
\mu_{w_k} = E[w_k] = 0
\]  
(5)

Variance of \( w_k \) is follow form Eq. (6)

\[
Q_w = E[w_k w_j^T] = \begin{cases} Q_w, & \text{for } k = j \\ 0, & \text{for } k \neq j \end{cases}
\]  
(6)

and measurement equation is follow form Eq. (7)

\[
z_k = Hx_k + v_k
\]  
(7)

We can design measurement on 2 Dimension follow form Eq. (8)

\[
\begin{bmatrix} \theta_k \\ \omega_k \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} w_{k-1} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} w_k
\]  
(8)

Equation (8) is a mathematical model of a system called measurement equation. Define \( v_k \) is measurement noise, Occurred in the mean was \( \mu_{v_k} \), we can define mean is follow form Eq. (9)

\[
\mu_{v_k} = E[v_k] = 0
\]  
(9)

In variance of \( v_k \) can follow form Eq. (10)

\[
R_v = E[v_k v_j^T] = \begin{cases} R_v, & \text{for } k = j \\ 0, & \text{for } k \neq j \end{cases}
\]  
(10)

by \( E[\cdot] \) is Expected Value Operator.

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**TABLE I. DISCRETE KALMAN FILTER TIME UPDATE EQUATIONS**

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Estimate covariance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted (a priori)</td>
<td>( \hat{x}<em>k = A\hat{x}</em>{k-1} + Bu_{k-1} )</td>
<td></td>
</tr>
<tr>
<td>Predicted (a priori)</td>
<td>( P_k = AP_{k-1}A^T + BB^T )</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II. DISCRETE KALMAN FILTER MEASUREMENTS UPDATE EQUATIONS**

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Estimate covariance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Kalman gain</td>
<td>( K_k = P_k H^T (HP_k H^T + R)^{-1} )</td>
<td></td>
</tr>
<tr>
<td>Updated (a posteriori)</td>
<td>( \hat{x}_k = \hat{x}_k + K_k (z_k - H\hat{x}_k) )</td>
<td></td>
</tr>
<tr>
<td>Updated (a posteriori)</td>
<td>( P_k = (I - K_k H)P_k )</td>
<td></td>
</tr>
</tbody>
</table>

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**V. ALGORITHM OF KALMAN FILTER DESIGN**

**A. Kalman Filter**

![Fig. 6, Block Diagram of normal kalman filter](image)

\[
A = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}; B = \begin{bmatrix} \delta \alpha \\ 1 \end{bmatrix}; \delta = 0.004;
\]

\[
u_k = \text{input of gyroscop}; Q = 0.4; R = 0.05;
\]

\[
z_k = \text{input of acceleromter}; H = \begin{bmatrix} 1 \\ 0 \end{bmatrix}; I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}
\]

**B. Series Kalman Filter**

![Fig. 7, Block Diagram of normal kalman filter for accelerometer](image)
\[ A = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}; B = \begin{bmatrix} \dot{\alpha} \\ 1 \end{bmatrix}; \dot{\alpha} = 0.004; \]

\[ u_t = \text{input of gyroscope}; Q = 0.005; R = 1; \]

\[ z_t = \text{input of accelerometer}; \]

\[ H = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}; I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \]

From Fig. 9, Kalman filter system found the graph that got from the estimation of gyroscope during the first phase is reliable estimation. Over time will find faulty signal of the time 0 to 30 seconds at the time. We did not do anything with the system then rotate slowly and faster and found the output of accelerometer be adjusted according to the measured angle but there are interfering signal ±1° while the graph of gyroscope tend to the movement of the graph as well as the system but the sum of gyroscope system did not according to the rotation system. After 30 - 42 seconds at a time make noise with vibration found the graph that get from the estimation of accelerometer is unreliable estimation while interference does not affect to the graph that get from the estimation of gyroscope but found error from the angle signals estimation of gyroscope. The graph of the sum signals between gyroscope and accelerometer found signals be changed according to the output of gyroscope and be the center of graph that get from the estimation of accelerometer but 30 to 42 seconds at a time found the perception signals of kalman filter have over shoot more than the estimation of gyroscope.

VI. SIMULATION RESULTS

The results of the simulation system, the tests were conducted by using kalman filter on accelerometer and gyroscope. The results were shown below.

Fig. 9, Output of kalman filter

Fig. 10, Output of kalman filter on accelerometer
From Fig. 10, in the design of series kalman filter system by bring the signal from the estimation of accelerometer estimated value of the kalman filter will find the graph is more smooth than the graph from average filter 15 information.

Fig. 11, Output of series kalman filter

From Fig. 11 and Fig. 12, A comparison of the signals were found both lines the estimated value of the kalman filter. There were characteristics of the signals were similar but different at 30 to 42 seconds at a time that there were high vibration. The graph that get from the estimation of series kalman will be lower over shoot than normal values to ±5° from ±15°.

VII. CONCLUSION

This project aimed to develop of tools to measure the angle to be more effective and more reliable by bring the estimation of kalman filter used by applying estimates status of the system. There are errors in estimating the minimum angle value. The experiments are designed by the series kalman filter introduce accelerometer to estimate the value in kalman filter. It will find the graph is more smooth than kalman filter which graph get from the estimation of accelerometer and gyroscope during the first phase is reliable estimation but over time make noise with vibration will find higher than normal over shoot affect to error in estimating the value of angle. When the comparison shows the estimation of series kalman filter in design accelerometer to kalman filter before use value output of system input series to kalman filter will be lower over shoot than normal kalman filter.

REFERENCES


