Contemporary Engineering Sciences, Vol. 7, 2014, no. 13, 637 - 647
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2014.4670

Fingers Bending Motion Controlled Electrical Wheelchair by Using Flexible Bending Sensors with Kalman filter Algorithm

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Abstract

Severely disabled people have difficulties to use joystick in controlling electrical power wheelchair because controlling the joystick requires a large force which is more than the threshold for severely disabled people. It is difficult for them to use joystick to provide precise commands to the electrical system of the wheelchair because they cannot control over the deck tilt angles of joystick precisely. Thus, the idea of using fingers bending motion to control electrical wheelchair provides a solution for this problem. However, trembling fingers motions from disabled people generate signal noise that cause the motion control of the wheelchair not running smoothly. The objective of this paper is to tackle signal noises that are caused by trembling fingers motion. Three filtering methods were conducted which are Moving Average, Low-Pass, and Kalman Filters. The results indicate that Kalman Filter has significantly improved the smoothness of fingers bending command signal to the electrical wheelchair as compared to Moving Average and Low-Pass Filter.

Keywords: Electrical Wheelchair, Flexible Bending Sensors, Kalman filter

1 Introduction

Mobility impairment is known as 'Locomotors" activity limitation which is a type of disability that is caused by incapability of legs and feet functions. Manual wheelchairs can only be helpful for those disabled people who are still able to maneuver the wheelchair. However, if a person is suffering from partial tetraplegia, sclerosis, Parkinson's disease, and stokes, he or she might lose most of the control ability to the wheelchair including hand movements. Hence, a conventional joystick controller for the electrical-powered wheelchair might be beneficial for the case. Unfortunately, controlling the joystick requires a large force which is more than the threshold for severely disabled people. Even though a power assisted joystick does not need much force to control, it is still a very difficult task for physical disabled people to control over the deck tilt angles of joystick precisely. For that reason, joystick controllers of the electrical-powered wheelchair might not be helpful. Therefore, researchers have proposed several types of controlling system such as voice recognition system, vision camera for head gesture detection, EEG (Electro-Encephalo-Gram) for brain signal detection, EOG (Electro-Oculo-Gram) for eye tracking and EMG (Electro-Myo-Gram) for muscle movement detection. However, all the methods mentioned above require high costs in purchasing and also maintenance. From the cost-effective consideration point, the idea of using fingers bending motion to control electrical wheelchair is an optimal solution in term of cost-effectiveness.

However, most of the disabled people will have the problem of trembling motion in fingers bending. They have the difficulty to control the movement of electrical wheelchair because the trembling motion is causing serious signal noise to the system. To overcome this problem, the implementation of Kalman Filter algorithm has been proposed to tackle the signal noises caused by trembling motion of disabled people and able to discern the difference between noises and dynamic pattern of the signals in order to capture the intention commands of their fingers motions.

2 Experimental Platform

The experimental platform consists of a fingers bending motion controller that is built by using flexible bending sensors which are attached to a hand-glove as shown in Figure 1. The completed platform is a custom-made wheelchair mechanism with differential drive system as shown in Figure 2.

Flexible bending sensor is a long resistor with its resistance value proportional to the change in bending angle. Flexible bending sensor is widely used in robotic design, gaming and medical device. A flexible bending sensor is able to function well in the range of zero degree to 180 degree of bending angle and operating temperature of -30^{0}C to 80^{0}C. The bending resistance range is from 45k ohms to 125k ohms and its lifetime up to one million bending times. Figure 3 shows the various bending degree of sensor gives different resistance value. For example, a flexible bending sensor gives a resistance value of 39.2k ohms when under flat condition at 180 degree. At 120 degree bending angle, the resistance value is 68.5k ohms while at 90 degree bending angle gives 125k ohms.

Figure 1. Fingers Bending Motion Controller[1]

Figure 2. Wheelchair Mechanism with Differential Drive System

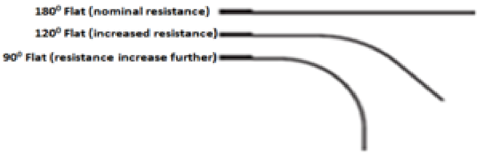

Figure 3. Bending Degree of Bending Sensor[2]

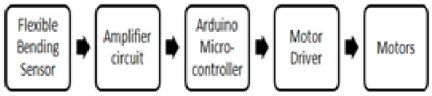

Figure 4. System Control Block Diagram

The system control block diagram is shown in Figure 4. Flexible bending sensors give input signals to an Arduino microcontroller through an amplifier circuit, then the Arduino microcontroller process the inputted signals and gives commands to the motors through motor drivers. Figure 5 shows the system components of the fingers bending motion controlled electrical wheelchair.

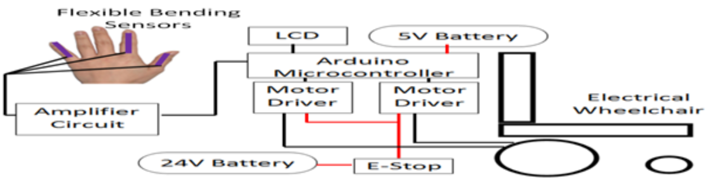

Figure 5. System Components of the Fingers Bending Motion Controlled Electrical Wheelchair

3 Proposed Solution

The proposed solution is to handle signal noise arise from the unwanted trembling finger bending motion of disabled people when controlling an electrical wheelchair. To overcome this problem, Kalman filter algorithm has been proposed to filter out the noise that caused by trembling motion of disabled people and able to discern the difference between noises and dynamic pattern of the signals in order to capture the intention commands of their fingers motions.

Kalman filter is a data fusion algorithm; it is not only a data fusion algorithm but also a state estimator which can perform the estimation of the past, present and future states, even dealing with some uncertainty in the process model[3]. One of the most famous application example of Kalman filter is Apollo navigation system that sent the first man to the moon[4]. Hence, Kalman filter is now used in every satellite navigation device, autonomous system and mobile robots.

When comparing Kalman filter to other filtering algorithms such as average filter, moving average filter, and Low-pass filter, Kalman filter is more than a filtering algorithm that filtering noises, but it also provides estimation of parameter which acts as an optimal state estimator that minimizes the variance of the state estimation error with Gaussian error statistics[5], [6].

Another filtering algorithm is average filter which can remove noise by averaging. However, it is also remove dynamic pattern of the signals at the same time. Hence, moving average filter is introduced to remove noise and keep the dynamic pattern of the signals. Nevertheless, moving average filter has its limitation due to the lack of ability in discernment between noises and dynamic pattern of the signals. To discern the noises, one of the ways is to discern from the signal frequency band. It is because in many cases, the signals are in low frequency band while on the other hand noises are in high frequency band. Therefore, Low-pass filter is applied to pass low frequency signal (signal to be measured) and blocks high frequency signals (noise) [7].

In spite of this, Low-pass filter cannot handle any uncertainties in the process model, for example, disturbance of signals that have discontinuity problem. In this case, Kalman filter comes in at the correct position because it is not only filtering noise and smoothing signal, but it also estimates or predicts the missing signals that caused by discontinuity problem. As a result, Kalman filter is suitable for the application because it can filter out the noise that caused by trembling motion of disable people and able to discern the difference between the noises and dynamic pattern of the signals in order to capture the intention commands of their finger motions. Whenever discontinuity or disturbance of signal occurs, Kalman filter can predict the intention command from disabled people’s fingers motion.

To design a Kalman filter, it starts with the linear state model of the system, fingers bending motion controller. In this case, Kalman filter is applied to each flexible bending sensor (bending angle, θ_i) to obtain a good estimation of each of the (bending rate, $\Delta\theta_i$). These bending rates will be used to control the movement of electrical wheelchair. For linear state model, as denote that:

$$x_1(t) = \theta_i(t)$$

$$x_2(t) = \Delta\theta_i(t) \qquad (1)$$

Therefore, the state variables are:

$$x_k = \begin{Bmatrix} x_1(t) \\ x_2(t) \end{Bmatrix} \qquad (2)$$

The system model is:

$$x_k = Ax_{k-1} + w_{k-1}$$

$$Where,\ A = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} \quad (3)$$

Discretizing equation (3) to get:

$$x_k = e^{AT_s}X_{k-1} + W_{k-1} \quad (4)$$

For the measurement equation of the system model, define as follow:

$$z_k = Hx_{k-1} + v_{k-1}$$

$$Where,\ H = \begin{pmatrix} 1 & 0 \end{pmatrix} \quad (5)$$

As for Kalman filter error covariance matrices such as Q, R and P are to be obtained through trials and errors. From the experiment, tuned following parameters for the error covariance matrices.

$$Q = \begin{pmatrix} 0.001 & 0 \\ 0 & 0.003 \end{pmatrix}$$

$$R = 0.08 \quad (6)$$

$$P_{k-1,ini} = 1 \cdot I_{2x2}$$

The Kalman gain K_k, prediction of the error covariance P_k^-, estimation of the error covariance P_k, can be obtained through the following formulas respectively.

$$K_k = P_{k-1}^- H^T (HP_{k-1}^- H^T + R)^{-1}$$

$$P_k^- = AP_{k-1}A^T + Q \quad (7)$$

$$P_k = (1 - K_{k-1}H)P_{k-1}^-$$

With the setting of system model and Kalman filter's parameters, the computation process of Kalman filter can be proceed and it is applied to each flexible bending sensor. Figure 6 shows the computation process of Kalman filter. Kalman filter's computation process involves two major stages. First stage is the prediction state, it starts with the system model of the finger bending sensor (step a). After that, the prediction of the error covariance P_k^- is to predict the error characteristic of finger bending sensor (step b). For the first iteration of the computation process, the initial estimate values $\hat{x}_{k-1}, P_{k-1}$ will be inputted to the prediction state. Second stage is the measurement update state, the Kalman gain will be computed and it is determined by error covariance matrices such as Q, R, and P_k^- (step c). The increase of R and decrease of Q will make the Kalman gain towards higher proportional of estimation and lower proportional of sensor measurement, whereas the decrease of R and increase of Q will make the Kalman gain towards lower proportional of estimation and higher proportional of sensor measurement. After that, Kalman gain will be applied to update the estimation of sensor measurement with the impact of the error covariance matrices Q, R, and P_k^- (step d). The estimation of the error covariance $P_k$will be updated by Kalman gain (step e). Finally, the latest value $\hat{X}_k, P_k$ of will be inputted to the prediction state for next iteration. With the iterations of computation process continues, Kalman filter will be able to able to discern the difference between noises and dynamic pattern of the signals in order to capture the intention commands of their fingers motions.

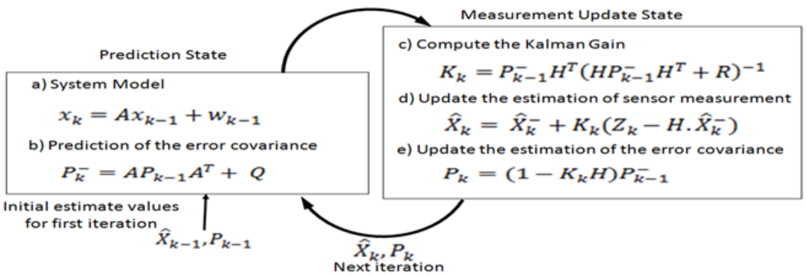

Figure 6. The computation process of Kalman filter

The mathematics models of Kalman filter applied to flexible bending sensor is programmed to Arduino based microcontroller in Java programming language. Subsequently, the data collection can be done and presents in next section.

4 Discussion of Results

The experiments involve capturing a trembling finger bending motion with flexible bending sensor which is attached to the finger; hence raw data of finger's bending degree versus time would be generated. After that, the raw data of flexible bending sensor's inputs will be filtered by different types of filtering algorithms so as to compare the performance of each filtering algorithm. These filtering algorithms are Moving Average Filter, Low-Pass Filter, and Kalman Filter.

The equation of Moving Average is defined as[7]:

$$\bar{x}_k = \frac{x_{k-n+1} + x_{k-n+2} + \cdots + x_k}{n} \qquad (8)$$

The equation of Low Pass Filter is defined as[7]:

$$\bar{x}_k = \alpha \bar{x}_{k-1} + (1 - \alpha) x_k \qquad (9)$$

The first experiment was carried out by capturing a finger trembling motion whilst the disabled people have not yet bent their fingers to give command to the controller but at the same time their fingers are trembling. The purpose is to identify the effectiveness of each filtering algorithm in filtering out trembling motion signal noise. Figure 7-10 show the results from the 1st experiment. Figure 7 shows the raw data of a finger trembling motion signal which comprises of bending degree versus time. Figure 8 & 9 show the filtered signal by using Low-Pass Filter and Moving Average Filter. Figure 10 shows the filtered signal by using Kalman Filter and it shows the bending degree is almost constant after the filtering. This applies that Kalman Filter has literally performed better than other algorithms i.e. Low Pass Filter.

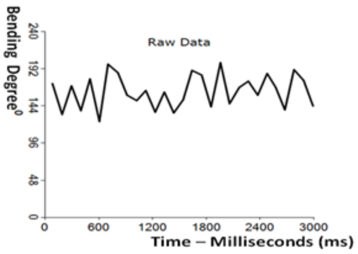

Figure 7. Experiment 1: The raw data (bending degree versus time)

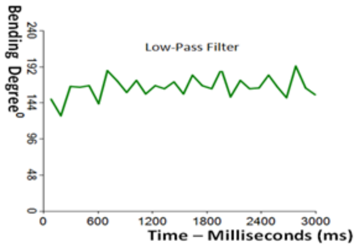

Figure 8. Experiment 1: The filtered signal (bending degree versus time) with Low Pass Filter

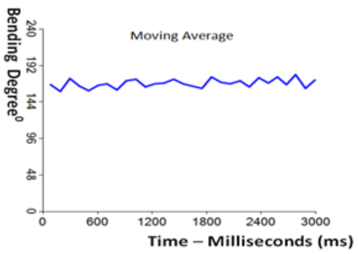

Figure 9. Experiment 1: The filtered signal (bending degree versus time) with Moving Average Filter

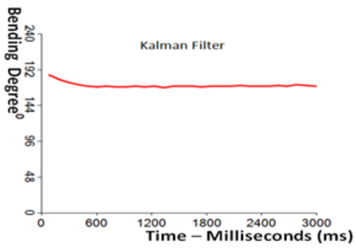

Figure 10. Experiment 1: The filtered signal (bending degree versus time) with Kalman Filter

The measurement of the effectiveness of the filtering algorithm can be determined by coefficient of determination R-squared[8], where a higher value of R-squared is indicating a smoother of result in finger bending controlling. The equation of coefficient of determination R-squared is defined in [8]:

$$R^2 = \frac{SS_{reg}}{SS_{tot}}$$

Where,

$$SS_{reg} = \sum_{i=1}^{n}(f_i - \mu)^2 \text{, the regression sum of squares}$$

$$SS_{tot} = \sum_{i=1}^{n}(y_i - \mu)^2 \text{, the total sum of squares} \qquad (10)$$

$$\mu = \frac{1}{n}\sum_{i=1}^{n} y_i \text{, mean value}$$

Table 1 shows the smoothness values of each filtering algorithm for experiment 1. The improvement of smoothing percentage of filtered signals for Moving Average Filter, Low-Pass Filter and Kalman filter are 27.48%, 16.56% and 77.77% respectively. This shows that Kalman Filter has the best output performance with the highest value in coefficient of determination R-squared, which it has successfully removed high frequency of signal noise. Although the Moving Average Filter and Low-Pass Filter have also reduced the frequency of signal noise, the results are less significant as compared to Kalman Filter. The comparison of different algorithms used in the 1st experiment is shown in Figure 11.

Table 1. The smoothness values of each filtering algorithm for experiment 1

	Raw Data	Moving Average	Low-Pass Filter	Kalman Filter
R-Squared	0.513	0.654	0.598	0.912
Improvement (%)	-	27.48	16.56	77.77

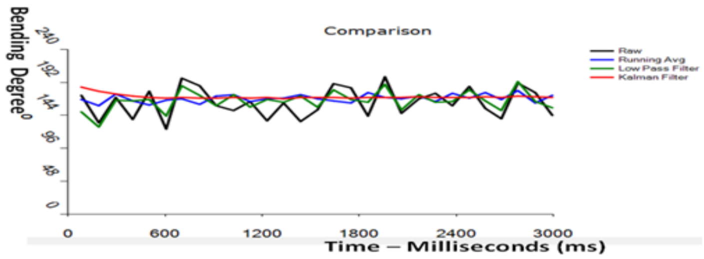

Figure 11. Experiment 1: The comparison of different algorithms used (bending degree versus time)

The second experiment was carried out by capturing a finger bending motion with trembling when the disabled people are giving command to the controller with real intentional of bending their finger from 180 degree to 50 degree finger's bending angle. The purpose is to identify the effectiveness of each filtering algorithm in capturing the real intentional of bending finger's command (from 180 degree to 50degree) and at the same time it is filtering the signal noises. Figure 12 shows the raw data of second experiment 2. Figure 13, 14, and 15 show the filtered signal (bending degree versus time) by using Low-Pass Filter, Moving Average Filter, and Kalman Filter.

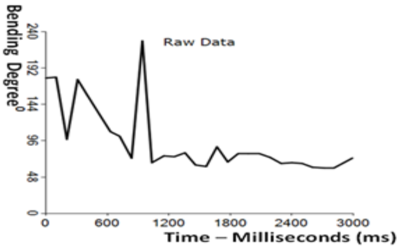

Figure 12. Experiment 2: The raw data (bending degree versus time)

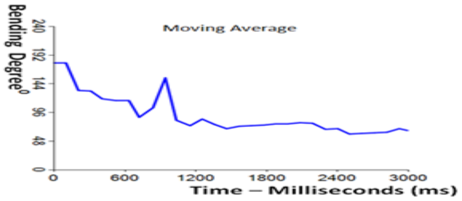

Figure 14. Experiment 2: The filtered signal (bending degree versus time) with Moving Average Filter

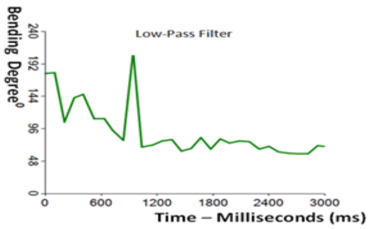

Figure 13. Experiment 2: The filtered signal (bending degree versus time) with Low-Pass Filter

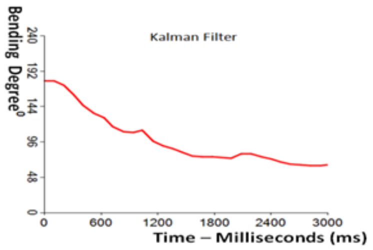

Figure 15. Experiment 2: The filtered signal (bending degree versus time) with Kalman Filter

Table 2 shows the smoothness value of each filtering algorithm for experiment 2. The improvement of smoothing percentage of filtered signals for Moving Average Filter, Low-Pass Filter and Kalman filter are 21.41%, 10.10% and 69.70% respectively. It shows that Kalman Filter is the best filtering algorithm to apply in fingers bending motion controlled electrical wheelchair as it has the highest value of coefficient of determination R-squared. From the results of experiment 2, it shows that Kalman Filter has not only filtered out the noise signal but also able to capture the real intentional of bending finger's command as the sensor bending trend is shown clearly in Figure 15, where the filtered signal has a smooth line from 180^0 degree to 50^0 degree finger's bending angle. Besides, Kalman Filter also removed the unwanted spike signal, whereas the Moving Average Filter and Low-Pass Filter are not able to remove the unwanted spike signal. The comparison of different algorithms used in the experiment 2 is shown in Figure 16. It shows that Kalman Filter has successfully removed the unwanted spike signal.

Table 2. The effectiveness of each filtering algorithm and their smoothness value

	Raw Data	Moving Average	Low-Pass Filter	Kalman Filter
R-Squared	0.495	0.601	0.545	0.840
Improvement (%)	-	21.41	10.10	69.70

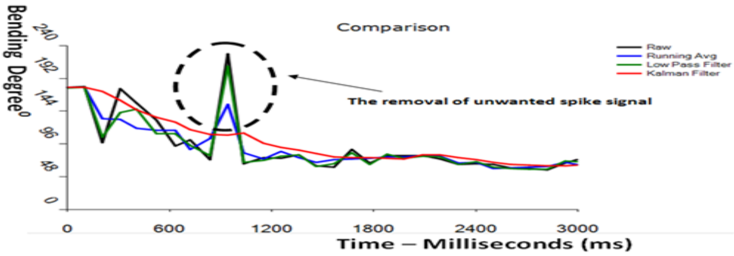

Figure 16. Experiment 2: The comparison of different algorithms used (bending degree versus time)

5 Conclusion

From the results, it shows that Kalman filter algorithm is suitable for fingers bending motion controlled electrical wheelchair because it can filter out the noise that caused by trembling motion of disabled people, remove unwanted spike signals, and able to discern the difference between the noises and dynamic pattern of the signals in order to capture the intention commands of their fingers motions. The results indicate that Kalman Filter has significantly improved the smoothness of fingers bending command signal to the electrical wheelchair as compared to Moving Average and Low-Pass Filter method. In the future, we aim to integrate fingers bending commands (with Kalman Filter) and artificial neural network so as to customize the signal patent recognition of particular disabled people.

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Received: May 1, 2014