Indian Journal of Chemical Technology
Vol. 26, May 2019, pp. 274-278

Improving estimation of body lengths using extended Kalman Filter for squat movement

Hüseyin Eski*[,1], Ümit Kocabıçak[2] & Ertuğrul Gelen[3]
[1,2]Computer Engineering Department, Faculty of Computer and Information Sciences, Sakarya University, Sakarya, Turkey.
[3]Education of Coaching Department, Faculty of Sport Sciences, Sakarya Applied Sciences University, Sakarya, Turkey.
E-mail: heski@sakarya.edu.tr

Received 20 February 2019; accepted 18 April 2019

Modeling and analyzing of human movements has become easier with the development of sensor technologies. Human movements can be modeled using image processing software with depth and motion sensors in 3D. Measurement errors are also observed in motion detection sensors as in most systems. Special filters have to be developed for each system in order to minimize this error rate and obtain more realistic measurements. Kalman Filter is a well-known method that is commonly used to minimize this type of measurement errors. In this study, the actual body lengths (upper arm, forearm, lower leg, upper leg) are measured and obtained from the human motion sensor. Kalman Filter and Extended Kalman Filter are applied to the obtained data from human motion sensor. All measurements are compared with the actual body lengths and error rate is calculated as using Mean Absolute Percentage Error (MAPE). Kinect data are compared with actual lengths and error rates were calculated at 20%, when the Kalman Filter is applied, the error rate decreased to 14%, while when the Extended Kalman filter is applied, it dropped to 8%. Human motion sensor data have been improved with using Extended Kalman Filter. Thus, actual measurements of candidatescan be easily obtained with only one useful sensor without taking any actual measurements by saving time and budget.

Keywords: Kalman filter, Extended Kalman filter, Kinematic analysis, Squat movement, Human motion analysis

With the rapid development of computer vision technology, human motion capture and analysis are widely used in many research areas, such as health, ergonomics, sports and security. Some information such as the location and position of person, and coordinates of joints should be known to analyze human movements.

Such as marker usage, wearable inertial sensors and computer vision based algorithms are effectively used in the motion detection in recent studies. Marker usage[1-4] and wearable inertial sensors[4-7] are widely used in the digitization of limited inland and simple movements, especially in the film industry, increased reality and simulation applications. It is known that wearable inertial sensors have limited mobility and are not suitable for large areas. In the case of marker usage, markers can not be detected from time to time and measurement is not possible. In addition to these, the cost of using multiple cameras is very high. When image processing management is used from the videos; the person is asked to mark the joint points individually by the user, resulting in workload and time loss.

Furthermore, movement analysis of disabled people with the help of these technologies and physical therapy methods are being developed[5,8,9]. For these systems, specially equipped spaces and high costs are required. It can also be installed only on certain health campuses due to the cost and low portability of the equipment used. In terms of sustainability as well as in the installation phase, there is a need for specialized human power in this area. The fact that the technological infrastructure costs are high, not easily accessible and portable, and that there are few specialists in this area, this field has become a necessity for new studies.

In the study of Guimarães *et al.*, ergonomic risk analysis was performed in 30 chemistry laboratories and working conditions were analyzed. As a result of the analysis, a number of ergonomic problems have been identified and they have developed a 3D virtual simulation tool for their solution. There ergonomic problems determined as repetitive and static awkward postures as squat movement, trunk and neck forward bending, shoulder flexion and abduction over 90 degrees; manual material handling activities, as lifting, carrying, pushing etc.[10]

Experienced staff working in the chemical industry often complain about musculo skeletal disorders, eyestrain and headaches. Aminuddin *et al*. have concluded that the squat movement is the highest risk movement in their study on the Work Posture Analysis Based on Rapid Upper Limb Assessment petrochemical factories[11].

In this study, measurement errors were improved by applying the Kalman Filter, which we have acquired with 3D data with Microsoft Kinect of human movements in terms of squat movement. Thanks to this study; an inexpensive, easily applicable system has been designed and the movement analysis of the people will be done in a more accurate way.

Obtaining data and methods

Microsoft kinect

Kinect is a low cost and easy to use human motion sensor. This sensor was originally developed by Microsoft for the Xbox 360 game console to play interactive games by sensing human movements ın 2010[12]. A beta version of the Software Development Kit (SDK) was released in 2011 to be developed by everyone. Kinect can identify the 3D location of 25 body joint using computer without markers(Fig. 1). The Kinect sensor automatically gathers the coordinate positions of the joints, when the user is detected[13]. Kinect evaluates each state independently of each other. There are some problems in the estimation of coordinates of joints that are not in the kinect vision area. In order to solve this problem and provide more realistic measurements, a filter is needed to estimate the next position by evaluating the previous states[14,15]. In this study, coordinate positions of the human joints was obtained by Microsoft Kinect Sensor.

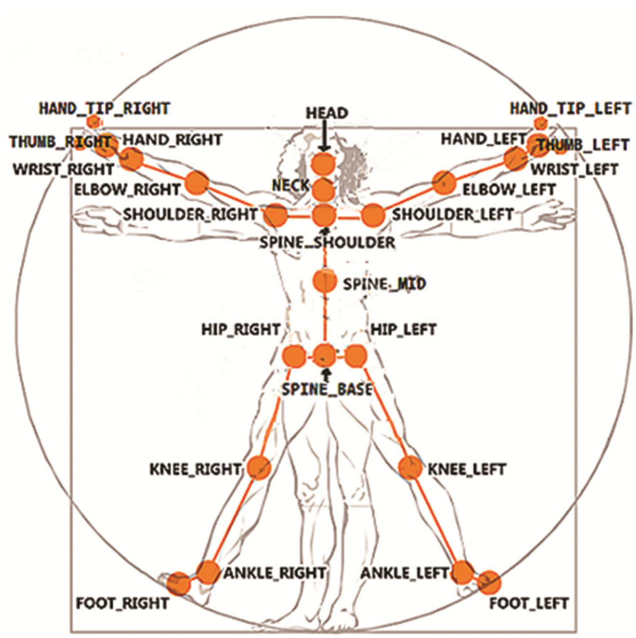

Fig. 1 — Skeleton positions relative to the human body[16].

Kalman filter

Kalman Filter was developed by Rudolf Emil Kalman in 1960 and is also known as "Optimal Estimator ", "Linear Estimator", "State Observer". The Kalman Filter was developed as a continuation of Wiener Filtration. The most important difference is that the input signal can be applied to non-stationary systems in the Kalman filter. This approach, which is coincidental with Bayes's Theorem, is now being applied in many fields. The Kalman Filter is also inspired by the least squares method to consider the error (error variance), not the fixed error[17-19]. The block diagram of the system is given in Fig. 2.

Kalman Filter tries to estimate the actual output and state of the system from input(u) that given to the system and the measured noise output (y). x is the state vector containing the terms of interest for the system (e.g., position, velocity) at time t. F is the state transition matrix, which applies the effect of each system state parameter at time t-1 on the system state at time t. B is the control input matrix, which applies the effect of each control input parameter in the vector u on the state vector.w is called process noise and the system represents ideal deviations from the model. w is the vector containing the process noise terms for each parameter in the state vector. The process noise is assumed to be drawn from a zero mean multivariate normal distribution with covariance. Also, y is the vector of measurements and H is the transformation matrix that maps the state vector parameters into the measurement domain. v is called measurement noise and represents the disturbances that occur in the measurement. In the Kalman filter; it is assumed that these noises affect the system as follows[12,20].

$$\hat{x}=Fx+Bu+w \quad \text{... (1)}$$

$$\hat{y} = Hx + v \quad \text{... (2)}$$

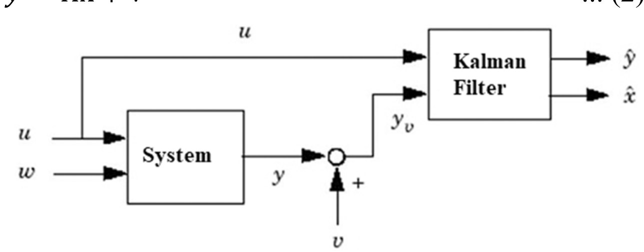

Fig. 2 — Kalman filter block diagram

$\hat{y}$ is the prediction that the Kalman Filter makes for the real output of the system and $\hat{x}$ is prediction for the state of the system.

The linear state space model is that the functions f (x, u, w) and h (x, v) are linear in state and input. These functions, which are linear, can be expressed by mathematical calculations of linear algebraic reduction F, B and H matrices. P is covariance of state vector estimate and Q is the process noise covariance matrix associated with noisy control inputs.This state of space model is shown as follows[20]:

$$x_{k+1} = f(x_k, u_k, w_k) \text{ ve } z_k = h(x_k, v_k) \quad ... (3)$$

$$x_{k+1} = F_k x_k + B_k u_k + w_k \quad ... (4)$$

$$z_k = H_k x_k + v_k \quad ... (5)$$

$$P_{k+1} = F_k P_{k-1} F_k^T + Q_k \quad ... (6)$$

Calculation and analysis process of this linear model is easy. The user has the possibility to investigate features such as controllability, observability, frequency response. Linear state models are based on linear processes or nonlinear processes and simply linearized through a first degree Taylor approach[21].

Kinematic analysis

The branch of science that tries to explain and evaluate the movements of biological entities using mechanical principles is called biomechanics[22]. In other words; it can also be expressed as a discipline in which biomechanical physical movements are transformed into numerical data. The biomechanical branch based on motion geometry is also called kinematics. Kinematics, interested in the position, velocity and acceleration of objects. The movements of person can be analyzed using this information. Accelerometers, gyroscopes, magnetometers, kinematic measurements without the need for images are the most basic systems.

Implementation

In this study, laboratory experts and students using the Sakarya University Chemistry Laboratory have been examined. The actual body lengths of the candidates are measured with the help of a caliper (Fig. 3). These candidates were made a squat movement, one of the basic movements for worker in laboratories, and the data of 25 joint points were obtained with the Kinect device. Forearm, upper arm, lower leg and upper leg data are calculated according to the 3D coordinates of the joint points from Kinect sensor. When the relation between the measured values of the Kinect instrument and the real data are observed by the mean absolute percentage error method, it is observed that the error rate is high. In this study, Kalman and Extended Kalman Filter, which are commonly used in correction of measurement errors, are designed.

When designing the Kalman filter, each anchor point is evaluated independently and a filter is applied to each. State equations and parameters were created by considering 3-dimensional coordinates, velocities and accelerations of each joint. The parameters of the designed system are set as follows:

State covariance matrix: $P = [0]_{9x9} =$

$$\begin{bmatrix} 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \end{bmatrix} \text{initially zero.}$$

Observation matrix: $H = [I_{[3x3]} 0_{[3x3]} 0_{[3x3]}] =$

$$\begin{bmatrix} 1&0&0&0&0&0&0&0&0 \\ 0&1&0&0&0&0&0&0&0 \\ 0&0&1&0&0&0&0&0&0 \end{bmatrix}$$

State transition

$$\text{matrix}: F = \begin{bmatrix} I_{[3x3]} & \Delta t I_{[3x3]} & 0.5\Delta t^2 I_{[3x3]} \\ 0_{[3x3]} & I_{[3x3]} & \Delta t I_{[3x3]} \\ 0_{[3x3]} & 0_{[3x3]} & I_{[3x3]} \end{bmatrix}$$

$$F = \begin{bmatrix} 1&0&0&\Delta t&0&0&0.5\Delta t^2&0&0 \\ 0&1&0&0&\Delta t&0&0&0.5\Delta t^2&0 \\ 0&0&1&0&0&\Delta t&0&0&0.5\Delta t^2 \\ 0&0&0&1&0&0&\Delta t&0&0 \\ 0&0&0&0&1&0&0&\Delta t&0 \\ 0&0&0&0&0&1&0&0&\Delta t \\ 0&0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&0&1 \end{bmatrix}$$

Fig. 3 — Holtain abdominal caliper

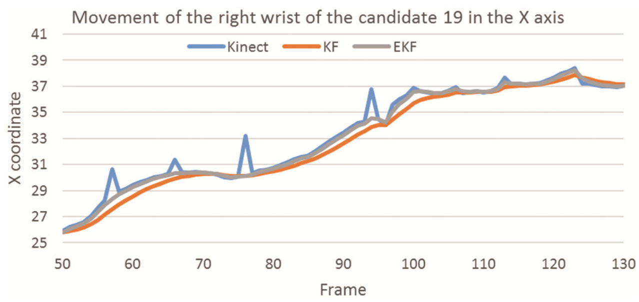

Fig. 4 — Frame and x coordinates graph of the right wrist

Table 1 — X coordinates of the right wrist

Frame Number	Kinect Result	Estimation from KF	Estimation from EKF
93	34,26	33,54	34,1
94	36,77	33,87	34,5
95	34,49	34,04	34,5

State Vector: $X=[X_x\ X_y\ X_z V_x V_y V_z\ A_x A_y\ A_z]^T$(X: position, V: velocity, A: acceleration)

The obtained coordinates of the right wrist joint of candidate number. 19, the value of each frame in the x coordinate, is given in Fig. 4. When the 94th frame is examined, it is observed that the x-position is incorrectly measured by Kinect. When we look at the x coordinates in Table 1, it is not possible for the hand to descend to the coordinates of 36, 77 and there is an incorrect measurement. Kalman filter and expanded kalman filter were applied to the system to eliminate such measurement errors. Kalman filter is suitable for linear systems, so as to make a linear motion predicted. in the extended Kalman filter, which is more suitable for non-linear systems, it minimizes incorrect measurement and is minimally affected by position change.

Conclusion

In this study, the squat motion of the experts and students using Sakarya University Chemistry Laboratory was investigated and Microsoft Kinect was used in the motion analysis. Measurement errors were encountered when the actual length data of candidates was compared with Kinect data. Kalman and Extended Kalman Filter are designed to eliminate measurement errors in the system. The squat movement of the candidates; Kinect data were compared with actual lengths and error rates were calculated at 20% using the mean absolute percentage error method. To reduce this error to admissible rates; Kinect data were applied to the Kalman Filter and Extended Kalman Filter. When the Kalman Filter was applied, the error rate decreased to 14%, while when the Extended Kalman Filter was applied, it dropped to 8%. When the squat motion of the candidates is examined, the position, velocity and acceleration information of the right wrist do not show linearity. Because of this reason, the Extended Kalman Filter used in non-linear systems produced a better solution.

In this study, it was observed that when the Extended Kalman Filter was applied to Kinect received, the error rate decreased to acceptable levels. Thanks to this work, Kinect can be used for realistic measurements at low cost; a system was implemented in which real-time kinematic analysis could be performed without wearing any wearable inertial sensors or markers.

In this study, the squat movement, which is a movement in which chemical laboratory workers are exposed to ergonomic risk, is discussed. Kinematic analysis were performed using kinect technology with the help of human motion sensor. Reliable data obtained by this study has been enabled to be used in ergonomic risk analysis. This study is expected to guide the developers of ergonomic risk assessment software.

References

1 Poppe R, *Comput Vision Image Understanding*, 108 (2007) 4.
2 Chen L, Wei H & Ferryman J, *Pattern Recognit Lett*, 34 (2013) 1995.
3 Wang X, Chen Q & Wang W, *Comput Math Methods Med*, (2014).
4 Moeslund T B, Hilton A & Krüger V , *Comput Vision Image Understanding*, 104 (2006) 90.
5 Lo Presti L & La Cascia M, Pattern Recognit, 53 (2016) 130.
6 Culmer P R, Levesley M C, Mon-Williams M & Williams J H G, *J Neurosci Method*, 184 (2009) 184.
7 Kaviani S, Salarieh H, Alasty A & Abediny M, *Sci Iran*, (2017).
8 Zhou H & Hu H, *Biomed Signal Process Control*, 3 (2008) 1.
9 Kale G V & Patil V H, *Int J Ambient Computing and Intelligence*, 7 (2016) 75.
10 Guimarães C, Cid G & Zamberlan M *Occupational Safety and Hygiene*. (2013) 333.
11 Aminuddin M, Sahroni T R, Smaz N & Yudistira J, *Work Posture Analysis Based on Rapid Upper Limb Assessment (RULA) for Operator Cellroom Electrolyser*, (2018) 2625.
12 Mobini A, Behzadipour S & Foumani M S, *Sci Iran*, 24 (2017) 191.
13 Sheu J-S & Wang K-C, *Sci Iran*, 22 (2015) 1501.
14 Atrsaei A, Salarieh H & Alasty A, *J Biomech Eng*, 138 (2016) 091005.
15 Dutta T, *Appl Ergon*, 43 (2012) 645.

16 “Microsoft Corp. Kinect for Xbox 360”, *Microsoft*. https://msdn.microsoft.com/en-us/library/microsoft.kinect.jointtype.aspx

17 Gündüz N, Başar E & Aydin C, *Acta Phys Pol A*, 128 (2015) 203.

18 Özdemir A, Erdem Z & Usuman I, *Acta Phys Pol A*, 130 (2016) 228.

19 Tekin H O, Manici T, Altunsoy E E, Yilancioglu K & Yilmaz B, *Acta Phys Pol A*, 132 (2017) 967.

20 Kalman R E, *J Basic Eng*, 82 (1960) 35.

21 Orderud F, *Comparison of Kalman Filter Estimation Approaches for State Space Models with Nonlinear Measurements*, 2005.

22 Hatze H, *J Biomech*, 7 (1974) 189.