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# ESTIMATION OF THIRD FINGER MOTION USING ENSEMBLE KALMAN FILTER

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***Abstract.*** *Post-stroke is a stage a patient undergoes if the patient has had a previous stroke. Stroke is a big and serious problem. As the second most common cause of disability of people at age of over 60 years. For patients having experienced a stroke, rehabilitation is a way to make them able to do activities of daily living as before. Stroke Rehabilitation is a comprehensive medical management and rehabilitation (in medical, emotional, social, and vocational aspects) concerning disabilities caused by stroke through a neuro-rehabilitation approach with the aim of optimizing recovery. The finger prosthetic arm robot is one of the results of the health technology development to help accelerate the rehabilitation process specifically for finger movements. One of the efforts to develop a finger robot is to estimate the movement of the fingers, in this case the finger size used is taken from those of Javanese people in Indonesia as the data to be simulated. In this paper is an estimation of the finger motion,particularly that of the third finger of the right hand, conducted using the Ensemble Kalman Filter (EnKF) method. The simulation results produced the third finger motion estimates with an accuracy of around 92% - 99%.*

***Keywords:*** *Estimation, Thirdfinger, EnKF, Post-Stroke*

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## 1. INTRODUCTION

Stroke is a collection of sudden symptoms arising due to circulatory disorders in the brain (bleeding / blockage). Post-stroke is a stage a patient undergoes if the patient has had a previous stroke. Stroke is a big and serious problem as the second most common cause of disability happening to people of over 60 years old [1]. For patients having experienced a stroke, rehabilitation is a solution for them to regain their capability to do activities of daily living as they did previously [2].

Stroke rehabilitation is a comprehensive medical management and rehabilitation (in medical, emotional, social, and vocational aspects) concerning any disabilities caused by stroke through a neuro rehabilitation approach with the aim of optimizing recovery and or modifying any remaining symptoms so as to make those with stroke able to do functional activities independently, to adapt to the environment, and to achieve a quality life. One of the medical rehabilitation activities is the recovery of paresis sufferers [2]. Paresis is a condition characterized by weakness in body movement, or loss of part of body movement, for instance in stroke, a patient experiences hemiparesis on one part of one side of the body, namely one prosthetic arm. Hands and fingers are the most important and complex organs of the human body [3]. The muscles of such organs can perform the movements of our five fingers as desired without having to control them one by one.

In hand movement therapy, the strength of gripping an object is an important aspect that needs training so that such function be restored. Technology-based rehabilitation therapy provides a more interactive, effective and independent therapeutic exercise, compared to any conventional rehabilitation therapy. One way among others is by using robot technology to improve the patient's motoric muscle performance [4].

Finger robot is one solution to help accelerate the rehabilitation process specifically for finger movements, considering the finger is an important part of the human body playing a very important role in human movement to carry out various daily activities. One of the efforts to develop finger robots is a finger motion estimation. In this paper the finger size used is taken from those of Javanese people in Indonesia as the data to be simulated.

One reliable estimation method frequently used is the Ensemble Kalman Filter method. The EnKF method is very reliable for both nonlinear and linear models. The EnKF method has been frequently applied for motion estimation of the 3-DOF Autonomous Surface Vehicle (ASV) model [5] [6] , the 6-DOF Autonomous Underwater Vehicle (AUV) [7] [8]and nonlinear missile movement mode [9]. Th EnKF has been applied for estimation of profit [10] [11]and crude oil price [12]. And, in this paper an estimation of the finger motion, especially of the third finger of the right hand, is made by using the EnKF method. The simulation results are compared to observe accuracy based on the number of ensembles generated.

## 2. RESEARCH METHODS

### 2.1 Invers Kinematic Motion Modeling of 3 Joint Finger

Below is the analysis of the 3 joint finger prosthetic arm robot

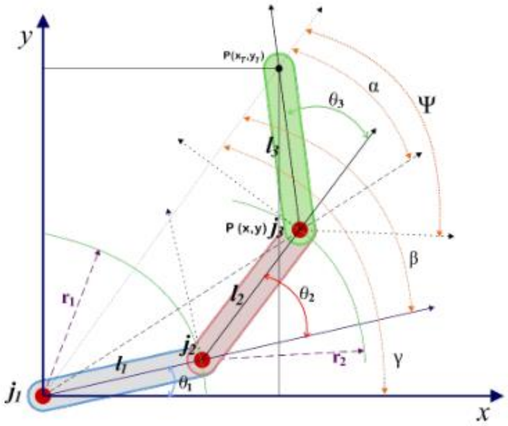


**Figure 1. Configuration of 3-Joint Finger Prosthetic Arm Robot**

Figure 1 shows that the 3-joint arm robot uses x and y coordinates in its working area. Like the 2-joint arm robot, the 3-joint arm robot uses forward kinematics as its equation analysis [13]. The angle $\psi$ is the angle of the third finger prosthetic arm in respect to the X-axis, as represented in equation 1 below.

$$\psi = \theta_1 + \theta_2 + \theta_3 \quad (1)$$

The following is the inverse kinematic model of the finger prosthetic arm robot:

$$\theta_2 = cos^{-1}\left(\frac{x^2 + y^2 - {l_1}^2 - {l_2}^2}{2l_1 l_2}\right)$$

$$\theta_1 = \tan^{-1}\left(\frac{y(l_1 + l_2 \cos\theta_2) - x.l_2 \sin\theta_2}{x(l_1 + l_2\cos\theta_2) + y.l_2 \sin\theta_2}\right)$$

$$\psi = \theta_1 + \theta_2 + \theta_3 = sin^{-1}\left(\frac{l_1(\cos\theta_1 - \sin\theta_1) + l_2(\cos(\theta_1 + \theta_2) - \sin(\theta_1 + \theta_2))}{2\, l_3}\right)$$

Below is the finger prosthetic arm robot with its fingers.

**Figure 2. Image of the arm robot with focus on its fingers**

## 3. RESEARCH METHOD

The research methodology of this study is as represented by the following flowchart of the algorithm of the Ensemble Kalman Filter below

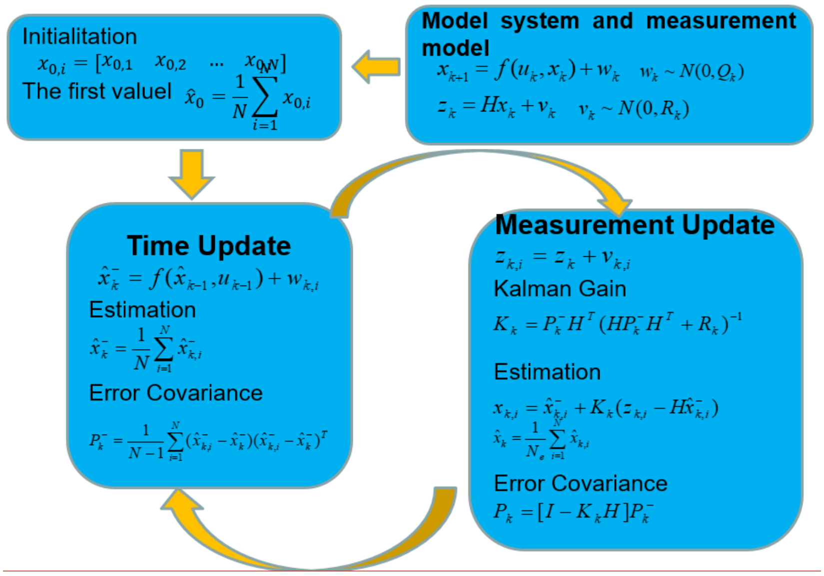


**Figure 3. The flowchart of the EnKF algorithm** [14] [15]

## 4. RESULTS AND DISCUSSION

The paper started by obtaining an inverse kinematic modeling of a finger prosthetic arm robot with 3 joints that match the structure of the human finger. This simulation was focused on the third finger, of which the average finger length used was taken from those of the Javanese people in Indonesia, whose finger length is around 7.8 – 8.3 cm. In this paper, the EnKF method was used by comparing the three simulation results, that is, by generating 400, 500 and 600 ensembles on the trajectory of the third finger movement in the form of a semicircle. The semicircular movement was chosen for the reason that all finger joints can move optimally. With a semi-circular movement with a diameter of about 7.8 cm, physical exercise on the third finger can be done well. The simulation results can be seen in Figure 4-6.

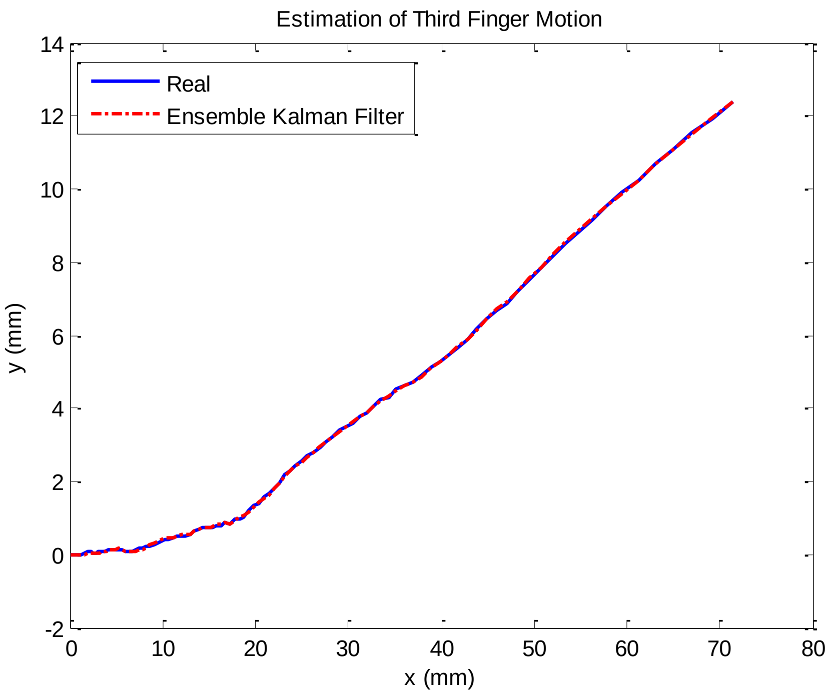


**Figure 4. Estimation of Third Finger Motion in XY Plane using 400 Ensembles**

In figure 4, it is formed by the movement of the X-axis and Y-axis positions, which can be observed that the Ensemble Kalman Filter method had a fairly high accuracy. Figure 4 is the simulation result by generating 400 ensembles. Especially for the movement of the X and Y axes shown in Figure 4-6, the accuracy is quite high. And, the estimation of the finger motion in the XY plane is to be compared to that of the motion of a semi-circle with a diameter of 7.8 cm. Figure 4 shows the simulation results by the EnKF method produced a movement resembling a semi-circle with a diameter of $\sqrt{7{,}1^2 + 1{,}2^2} = \sqrt{50{,}41 + 1{,}44} = \sqrt{51{,}85} = 7{,}2$ cm, so that overall if viewed from the diameter of about 7.8 cm, then by using the 400 ensembles, it has an error of about 7.6% and an accuracy of 92.4%

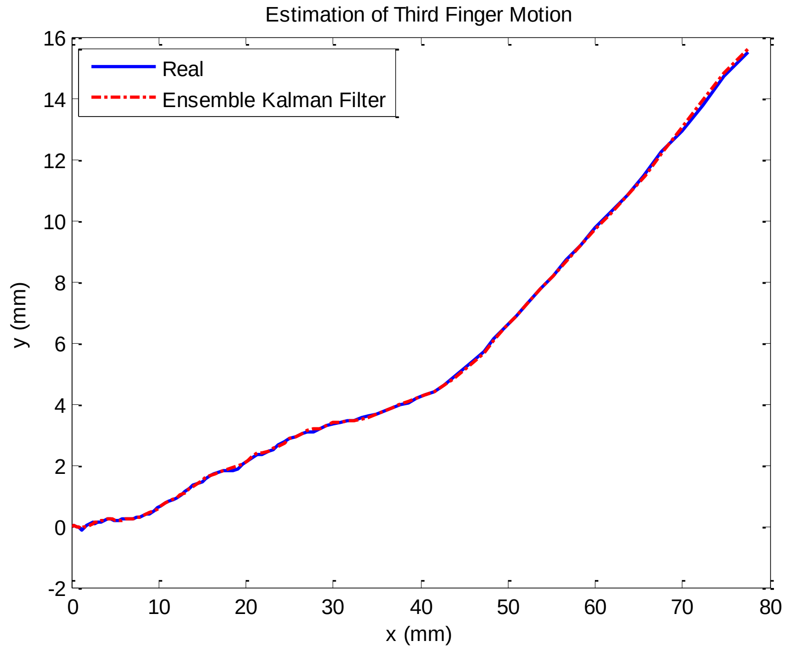


**Figure 5. Estimation of Third Finger Motion in XY Plane using 500 Ensembles**

Figure 5 shows that the simulation results by the EnKF method produced movement resembling a semicircular motion with a diameter of $\sqrt{7{,}7^2 + 1{,}5^2} = \sqrt{59{,}29 + 2{,}25} = \sqrt{61{,}54} = 7{,}84$ . So, overall if viewed from the diameter of about 7,8 cm, by using 500 ensembles it has an error of 0,51%, or in other words it has an accuracy of around 99,4%.

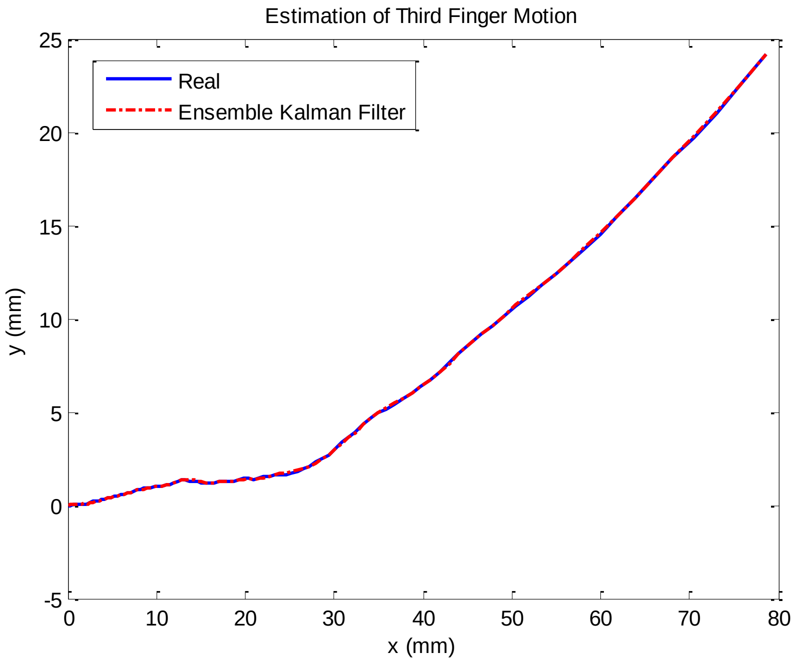


**Figure 6. Estimation of Third Finger Motion in XY Plane using 600 Ensembles**

Figure 6 shows that the simulation results by the EnKF method produced movement resembling a semicircular motion with a diameter of $\sqrt{7{,}8^2 + 2{,}4^2} = \sqrt{60{,}84 + 5{,}76} = \sqrt{66{,}6} = 8{,}16$ cm. So, overall if viewed from the diameter of about 7,8 cm, by using 600 ensembles, the results show an error of about 4,61% or an accuracy of 95,4%.

**Table 1. The accuracy rates of the third finger motion by EnKF method**

| | **400 Ensemble** | **500 Ensemble** | **600 Ensemble** |
|---|---|---|---|
| **XY Motion** | 92,4 % | 99,4% | 95,4% |
| **Simulation Time** | **7,6 s** | **10,2 s** | **12,8 s** |

In Table 1, it can be seen that by generating 500 ensembles, the results were more accurate than those by 400 dan 600 ensembles. However, for simulation time, generating 400 ensembles resulted in higher accuracy than generating 500 and 600 ensembles due to the factor of the number of ensembles generated. When the third finger size of Javanese people in Indonesia, generally of around 7,8 cm (as diameter) was used the reference of the semicircular trajectory, then the error for the XY motion using 400 reached about 7,6% and that for 600 ensembles was 4,61%, but for the XY motion using 500 ensembles, the error was about 0,51 %.

## 5. CONCLUSION

From the simulation results and analysis above, it was found out that the EnKF \ method was effectively applicable to estimate the movement of the third finger, especially the finger size of Javanese people in Indonesia, with an accuracy of around 92% - 99%. When using the 500 ensemble, it produced a small error of about 0.51%. The error was obtained after being compared to the average third finger size of the Javanese people in Indonesia, which is about 7.8 as the diameter of the movement forming a semicircular trajectory.

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