Simulation of Knee Joint Angle Estimation from EMG Signal for Post ACL Reconstruction Surgical Rehabilitation

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Abstract. Anterior Cruciate Ligament (ACL) rupture is one of the most common and severe sports injuries among the athletes caused by trauma. The standard treatment for ACL rupture patients is Reconstruction Anterior Cruciate Ligament (RACL) surgery, followed by rehabilitation lasting six to nine months. Consistent post-RACL medical rehabilitation can restore normal knee function. In this study, proposes a real-time simulation of knee joint angle estimation from electromyogram (EMG) signals for medical rehabilitation of RACL patients. Which is the continuation of this program is to be able to create an exoskeleton to increase the consistency and quality of medical rehabilitation of RACL patients. The method used to make this simulation is using LabVIEW software to simultaneous data collection between the EMG signal from the bicep femoralis muscle and the knee angle. The simultaneous data is processed using a Monte Carlo calculation to estimate the knee angle from the EMG signals. The LabVIEW simulation shows that the knee angle’s estimate was close enough to the measured knee angle and had a small time delay. It can be concluded that simulation of knee angle estimation from the EMG signal produces a good simulation and can be developed to the exoskeleton.

1. Introduction
Anterior cruciate ligament (ACL) is one of the four main ligaments in the knee. The ACL connects the femur and tibia bone. The function of the joint in general is to perform the movement on the body and as stabilization, where ACL controls the movement of the tibia towards anterior and inhibits the extreme ranges of tibia rotation [1].

ACL rupture is one of the most common and severe sports injuries among the athletes caused by trauma. These injuries often result in joint effusion, muscle weakness, altered movement, reduced functional performance, and the loss of a chance to play for entire season or more of sports. ACL rupture caused by direct or indirect contact with the knee. More than 70% of ACL injuries occur because a non-contact (without a direct blow to the knee joint). They usually happen due to landing from a jump or wrong technique when doing athletic activities such as basketball and soccer [2]. The insurance company report shows that in 5 years, there are 8215 total knee injury case claims with 31% ACL injuries [3]. Then, based on Public Health of Central Java from RSUD dr. Soetomo in 2012, the incidence rate of knee injury incidence was up to 49.4%. Meanwhile, the Public Health of West Sulawesi
report showed that the incidence rate of knee injury incidence was 38.9% [4]. In an injury report by the AFL in 2012, ACL injuries occur 38 cases per club each season in the United States [5]. Also, ACL injuries total between are 100,000 and 200,000 yearly [6]. Faltstrom research in 2016 showed that ACL injury on population aged 10-64 years old in the general Swedish occurs with an rate incidence of approximately 81/100,000 people/year, making this case the most common ligament injury [7].

The standard treatment for ACL rupture patients is Reconstruction Anterior Cruciate Ligament (RACL) surgery [8]. While there are a few ACL athletes can back to their activity/sport without RACL surgery. Furthermore, they are at a very high risk of a second knee injury. Kiapour research in 2014 also claims that RACL was the gold standard solution for ACL injuries, especially for the patients/athletes who wanted to return to normal sporting activities [2]. After RACL surgery, the patients should be followed by rehabilitation lasting six to nine months. Postoperative rehabilitation after RACL is consist of six phases that one of the targets is maintaining full ROM of the knee [9]. Longer rehabilitation programs are needed to restore strength of the knee before the patient return to activity. Furthermore, a return to participation decisions may need to include isokinetic knee-extensor and -flexor strength assessments [10]. Cavanaugh's research in 2017 said that, as the patient progresses through their rehabilitative programs, continually challenge the patient based on their goals, their levels of strength, amount of healing, and the given task's performance by the rehabilitation physiotherapist. In other words, the patient should complete a simple activity before advancing to more activity [11].

Based on several ACL cases and the treatment to return to the normal activity, this study proposes a real-time simulation of knee joint angle estimation from electromyogram (EMG) signals to improve the consistency and the quality of the post RACL rehabilitation treatment. Which is the continuation of this program is to be able to create an exoskeleton to complete a simple activity by self-rehabilitation, which will increase the recovery rate of medical rehabilitation of RACL patients.

2. Method

The method used to make this simulation consists of several stages, collecting EMG data and the angle from the knee joint, processing EMG data, modeling the knee joint angle, and integrate the Monte Carlo estimator algorithm using LabVIEW.

2.1. EMG and Angle’s Data Collection

Collecting the EMG and knee joint angle is carried out simultaneously. In this study, the data were collected from a subject who was 22 years old and had 65 kg weight. The scheme for taking EMG and knee angles data are showed in Figure 1.

During the device installation, the subject used an exoskeleton that was already installed with an Encoder angle sensor on the upper right lateral thigh. The exoskeleton is tied with straps at the medial and at the end of the thigh and the calf's base and medial. Then, a Myoware EMG electrode is placed on the medial femoral biceps muscle, with the ground from the EMG attached to the knee. After that, the angle sensor and EMG were connected to the NI myDAQ data acquisition.

Then, at the end of the subject's feet, a ± 4 kg load was tied to increase the torque on the legs so that the EMG signal was more apparent. Before collecting the data, the researcher arranged the LabVIEW program, such as pins, directory folders for data, and a sampling frequency at 1000 Hz. These are already qualified Nyquist rules [12]. When the data began to be recorded, the subject slowly started moving their legs extension and flexion movements repeatedly for about 20 seconds.

2.2. EMG Data Processing

At the EMG signal data processing stage, the EMG data will be processed by several processes. First, the EMG data will be filtered on its frequency, rectify, and smoothing. EMG data processing is carried out in order to obtain the information needed and to clarify the analysis [13].
2.3. Modelling and Estimating

After the EMG data and angle data are processed, the correlation between the two data will be examined. Furthermore, angular modeling of the EMG is carried out, the modeling is carried out using the curve fitting method. Monte Carlo is a method for estimating a value/state from the results of the simulation [14]. The estimation results carried out in this method depend on the model, and the probability density function of the data, the more simulations performed, the better the estimation results [15]. The Monte Carlo algorithm that has been compiled and then created in LabVIEW.

3. Results and Discussions

3.1. EMG and Angle Data Collection

The EMG and angles data collection were performed using LabVIEW. The data collection program consists of a block diagram as the program's core and a front panel to view and set the program [16], as seen in Figures 2a and 2b. At the beginning of the block diagram, the main acquisition initialization setting is given, such as the unit, channel, buffer size, frequency sampling, sample size, sample mode, pulses size, z index, timer mode, and the logging data mode. Then, the program's while loop consists of an analog read and counter reading function to read the measured EMG and angle data, timer, logging data, and the chart view the measured data. On the front panel, there's such a number control to setting frequency sampling, buffer size, sample size, pulses size, and timer. Also, there's a string control to set the directory of the logging data and chart to view the measured EMG and angle.

The EMG and angle data obtained in Figure 3 showed that when the subject lifts the knee to extension motion, the bicep femoral muscle is contraction, so does the angle rise. The subject can lift the leg with the load at a maximum angle of ± 70°. While in Kumar research in 2012 said that the knee joint's ROM is 141.7° [17]. It's different from the experiment because the position of the subject is in a sitting position, and data recording begins when the legs form an angle of ± 70° from the thigh. From one cycle of leg extension and flexion motion, it can be seen that the EMG data and angles are in the same pattern. At the end of the graph showed that the EMG signals are decreased because the muscle is getting fatigued.
Figure 2. LabVIEW Data Collection Program for (a) The Block Diagram and (b) The Front Panel
3.2. EMG Data Processing

In EMG signal measurements, noise is usually found. The noise contains information that is irrelevant to the original EMG signal state. The common noise found in EMG is power line interface (PLI) noise and motion artifacts, therefore a filter is needed to remove noise from the EMG [18]. This study, using a digital filter IIR Band Pass Filter type Butterworth Order 2 in the frequency range 20-500 Hz, according to Maeda (2012), the EMG frequency is in the 6-500 Hz frequency range, and the peak of EMG amplitude is at a frequency of 10-250 Hz [19]. Therefore, the range used is the frequency 20-500 Hz. Comparing to Christoph research in 2011, that filtering the EMG signals at the frequency 10-400 Hz [20]. Moreover, Dev experiments in 2015 was using IIR Notch filter to reduce the PLI [21]. In this study, the EMG signal is carried out by IIR Band Stop Filter order 2 in the frequency range 49-51 Hz to remove the PLI noise. After being filtered, the EMG data got rectify then smoothing using a moving average. The processing EMG data and the normalization with an angle are revealed in the figure 4(a) and 4(b).

3.3. Modelling and Monte Carlo

The correlation between EMG and angle data showed that the data had a relatively strong positive correlation. The modeling stage is performed using curve fitting toolbox in Figure 5. The result of modeling between EMG and angle is obtained \( f(x) = 7.71 -1869x + 1.895e+05x^2 - 5.532e+06x^3 + 7.606e+07x^4 - 4.964e+08x^5 + 1.232e+09x^6 \), with root mean square error (RMSE) of the model is 25.17°. The curve fitting method is chosen because it had a simple calculation and wanted to use Monte Carlo as model optimization. Triwiyanto in 2018 said that EMG signal give many random information such as angle, torque, angular speed, muscle condition [12]. Using several methods could extract the
angle information from EMG signals. Monte Carlo method is used because it used probability density function could interpret the angle from the simulations.

Figure 5. Curve Fitting Modelling Toolbox

3.4. LabVIEW Estimation Simulation
The simulation performed on LabVIEW consists of several stages, reading the processed EMG data and angular data. Then, the data is transferred to the Monte Carlo estimation system, with the transfer rate is the same with sampling frequency, which is 1000Hz. When the estimation system receives the EMG data and the angle, the system will calculate the angle estimation based on the EMG signal input and compare it with the models' angle estimation. The block diagram and LabVIEW front panel are exhibited in the figure 6(a) and 6(b).
The simulation shows that the estimation of angle from EMG signals using the Monte Carlo method had a good result. An average of RMSE estimation was $5.31^\circ$ compared with the model RMSE was $25.33^\circ$. Also, the simulation had a little delay between transferring the data and the estimation result.

Comparing other experiments that estimate angle from EMG on Triwiyanto in 2017, using the Kalman estimator to estimate elbow angle from biceps muscle, the estimated result angle has a good result with RMSE $6.9^\circ$ [22]. It also recommended that the method can be implemented in prosthesis or exoskeleton. Based on another research, this simulation is close enough to the reality because the EMG data and angles are transferred to the estimation system according to the data acquisition sampling frequency. It can also be seen that the delay time between the transfer time and the estimation system output.

4. Conclusions
This simulation shows that the knee angle's estimate was close enough to the measured knee angle with RMSE were $5.31^\circ$ and had a small time delay. It can be concluded that simulation of knee angle estimation from the EMG signal produces a good simulation and can be developed to the exoskeleton for post ACL rehabilitation.

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