2014 Ninth International Conference on Broadband and Wireless Computing, Communication and Applications

Controlling Mobile Robot Using IMU and EMG Sensor-based Gesture Recognition

Seong-Og Shin and Donghan Kim
Department of Electrical Engineering
Kyung Hee University
Yongin-si, The Republic of Korea
tmfb@naver.com

Yong-Ho Seo
Department of Intelligent Robot
Engineering, Mokwon University,
88 Doanbok-ro, Seo-gu, Daejeon, Republic of Korea
yhseo@mokwon.ac.kr

***Abstract*—In recent years of the field of robotics, various methods are developed for intimate relationship between people and robot. These methods include speech recognition as well as gesture-based interaction. This paper proposes a system that controls a mobile robot by recognizing the user gesture. The proposed system applies hidden Markov model (HMM) using inertial measurement unit and a single electromyography (EMG) sensor. HMM is known as the rich formula system, which can be applied to many applications including the gesture recognition. HMM is simply not only a gesture, but also can be applied to human robot interaction (HRI) very effectively. Thus, this paper uses the HMM to generate a familiar interaction between user and mobile robot. The body gesture is recognized using IMU sensor, which is easy to use for anyone. The mobile robot is then controlled according to the continuous incoming EMG command signal through Bluetooth, which is determined by the user gesture. Lastly, the HMM is applied as the method for determining the accuracy of user posture. In this way, more natural and intelligent gesture-based control system is implemented.**

***Keywords*—mobile robot; IMU sensor; EMG sensor; Hidden Markov Models(HMMs); gesture recognition;**

I. Introduction

Many subjects related to the communication between human and robot has been explored in recent years and a variety of research methods are continuously announced. Many user friendly interfaces have been introduced using speech, vision, gesture, etc. Among the studies using gesture, Mitra et al. have discussed the method that uses a variety of sensors to obtain a signal to determine the gesture pattern [1]. One of the objectives in this paper is to understand a hand gesture using IMU sensor and EMG signal, which is one of the biological signal that flows through the surface of user's skin. In order to achieve the natural and accurate gesture-based HRI system, this paper considers the characteristics of IMU and EMG. The combination of two sensors will increase the number of hand gestures and the accuracy of recognition system.

In recent years, the number of studies that apply biological signal – electromyograms (EMGs), electroencephalograms (EEGs), and electrooculograms (ECGs) – have been increased. As an example of EMG signal, the hand-free gesture recognition device, EMG-mouse, is introduced that does not need any conversation [2]. In addition, there is a research that controls a mobile RC car by distinguishing four types of gestures using a single EMG sensor [3]. Lastly, there is a research that assembles Rubik's cube and commands vocabulary in the virtual space using hand gestures by integrating multiple number of EMG sensors and 3-axis accelerometer sensor [4].

HMM is the most frequently used tool in gesture recognition due to the superior formula system in pattern recognition [5][6]. Thus, HMM is very effectively applicable to the HRI. In [5], the recognition rate of extracting a vector between each point of postures has been increased with 2-stage HMM by using Kinect camera sensor. In [3], the hand gesture has been distinguished by using multi-stream HMM with 3-axis accelerometer sensor and EMG signal. In [6], the recognition rate has been enhanced by using a single HMM.

In this paper, the hand gesture is extracted using an IMU sensor and a single EMG sensor. From the IMU sensor, the roll, pitch, and yaw data are received in real-time and the gesture is differentiated by comparing the difference in the angles. The average of EMG signals obtained through fast Fourier transform (FFT) is used as the reference point. In other words, the execution of robot control is depending on the magnitude of arm force. HMM is then applied in the proposed system to enhance the recognition rate between multiple gestures from user. More accurate biological signals can be obtained if multiple numbers of EMG sensors are used, but the user has the pressure to wear multiple sensors on one's arm. Thus, the experiment is simply performed by using a single EMG sensor on one arm.

II. Gesture Recognition System

A. Hand Gesture Recognition System

The proposed gesture recognition system measures the values of roll, pitch, and yaw in real-time using IMU sensor. Note that the 3-axis of continuously incoming output data from sensor is measured as Euler angle in degrees. As shown in Fig. 1, the recognized gesture is essentially divided into four gestures: turn left, turn right, forward, and backward. In order to obtain accurate data of IMU sensor, the arm is bent 90 degree as a default position (or home position). The first gesture (Fig. 1 Gesture 1) rotates the wrist in the counterclockwise direction to signify turn left motion. The second gesture (Fig. 1 Gesture 2) rotates the wrist in the clockwise direction to signify turn right motion. The third gesture (Fig. 1 Gesture 3) drops the arm down to signify forward motion. Lastly, the forth gesture (Fig. 1

978-1-4799-4173-5/14 $31.00 © 2014 IEEE
DOI 10.1109/BWCCA.2014.145

Gesture 4) raises the arm up to signify backward motion. The recognized gestures are composed of simple gestures, which can be mostly used by anyone intuitively. The mobile robot motion is controlled according to the gesture command when each gesture is taken.

The motion operating with EMG is implemented according to the muscle movement of inner arm. The control method using the muscle movement is introduced in [7], which sets 'Go' and 'Stop' commands using EMG signal from levator scapulae muscle. Similarly, as shown in Fig. 2, the proposed system divides the gesture into two by attaching the EMG sensor to the inside of the arm. The first gesture (Fig. 2 Gesture 5) is recognized as 'Start' command that starts to control the mobile robot according to the 3-axis data from IMU sensor in real-time. The second gesture (Fig. 2 Gesture 6) is recognized as 'Stop' command that changes the mobile robot into standby mode and stops receiving data from the 3-axis IMU sensor.

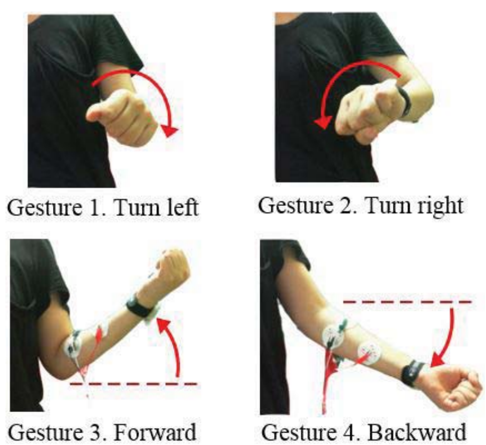

Fig. 1. 3D Accelerometer Gesture performance

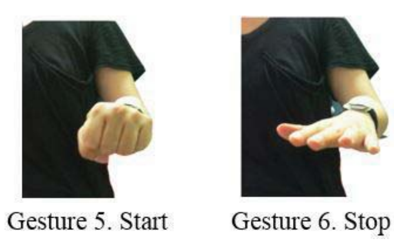

Fig. 2. EMG signal gesture performance

B. Overall Structure of Proposed System

This section describes the overall procedure of the proposed system as the sensor signal gets received and processed into gesture information, and then sent to mobile robot for control. Fig. 3 shows the flow chart of the proposed system.

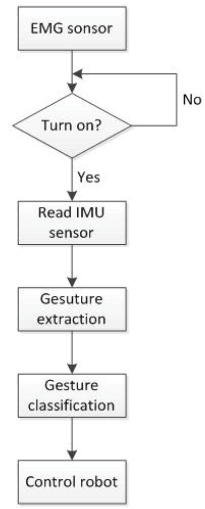

Fig. 3. The structure of hand gesture recognition system

EMG signal is detected by the sensor electrode in accordance with the movement of the arm muscles. The first is to preprocess the input raw data. The gesture movement is then represented as the angular value of input data from the IMU sensor. Lastly, the detected motion is determined by HMM classification, and lastly, the mobile robot performs the command according to the determined gesture.

The gesture from EMG signal decides the activation of gesture from IMU sensor. As shown in Fig. 2, the gesture from EMG signal is divided into two motions: clenching the fist and stretching the fingers. In order to determine these two motions, the EMG signal is converted using fast Fourier transform (FFT) and the average value of the magnitude of frequency response is calculated. This average value is set as a threshold value to execute the IMU gestures. In other words, the IMU gestures are either activated or deactivated based on the size of the threshold value. The average value of EMG signal is calculated as follows:

$$Mag_{EMG\_Avg} = SUM(Abs(FFT(x)))/N \tag{1}$$

where x and N represents the EMG input signal and the sampling number, respectively. Note that the input signal is sampled at the rate of 1 kHz in the proposed system.

Among roll, pitch, and yaw values received from the IMU sensor, the yaw value does not affect the motion in 2-D space. Thus, only roll and pitch values are used to generate gestures. The direction and speed of mobile robot are proportional to the angle of arm-twist, which are calculated by comparing the angular value of each axis and by using the absolute value of each vector, respectively. Its magnitude is calculated as follows:

$$Mag_{ACC} = \sqrt{(\theta_{roll})^2 + (\theta_{pitch})^2} \tag{2}$$

where θ_{roll} and θ_{pitch} represent the Euler angle of roll-axis and pitch-axis, respectively, in degrees.

In 'Gesture Classification', the gesture is classified by comparing the absolute value based on the point where the continuously received both roll angular data and pitch angular data become zero. Lastly, based on the reference gesture where the roll and pitch angles are changed, the four types of IMU position are marked.

HMM is applied to improve the gesture recognition rate. In the HMM, four types of IMU position are given as training data to distinguish the main gesture. The feature vector obtained through the HMM has the following four types of gestures as follows:

$$O = (dir\_CW, dir\_CCW, dir\_F, dir\_B) \tag{3}$$

where *dir_CW* 와 *dir_CCW* represent the clockwise direction and the counterclockwise direction, respectively. dir_F and dir_B denote the forward direction and the backward direction, respectively.

III. Experimental Results

A. Experiment Setup

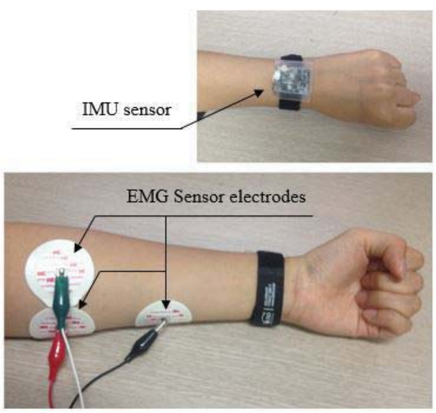

Fig. 4. Experiment setup of EMG sensor and 3-D accelerometer sensor

To verify the effectiveness of the proposed system, the experiment was conducted using C# and MATLAB. Fig. 4 shows the snapshot of attaching IMU sensor and the electrode of EMG sensor.

The IMU sensor used in this experiment is EBIMU24G, which is 2.4 GHz of AHRS wireless module and has 9-axis MEMS built-in sensor. Since the format of output gesture data can be configured, the Euler angles output was used in the experiment. Due to its size, 32.0 mm by 24.0 mm, it is also suitable for use with armband.

The EMG sensor is built such that the first range of sensor measurement was between 0.1 and 500 Hz. The second range, a low-frequency pass region, reduces the noise generated from 150 Hz to high-frequency, which allows measuring the biological signals below 150 Hz. The EMG signal was measured from the electrodes located inside the forearm.

Fig. 5 shows the snapshot of 'IRobot Create', which is used as mobile robot to control using wireless command signal. Since the serial packet can be sent through Bluetooth, the gesture command corresponding to the user gesture was sent to the robot to control its motion.

Fig. 5. Snapshot of IRobot Create mobile robot

B. Experiment Result

Arduino UNO was used as the microcontroller to convert the analog EMG signal to digital signal. The EMG signal received in Arduino was sent to PC using serial communication, which is then converted using FFT in MATLAB. The input data was sampled at 1 kHz and the average of 128 samples of FFT EMG signal was used as the threshold value to activate the gesture motion. When the detected force from EMG sensor was greater than the threshold value, the proposed system started to recognize the user gesture, which was classified based on the value of 3-axis IMU sensor.

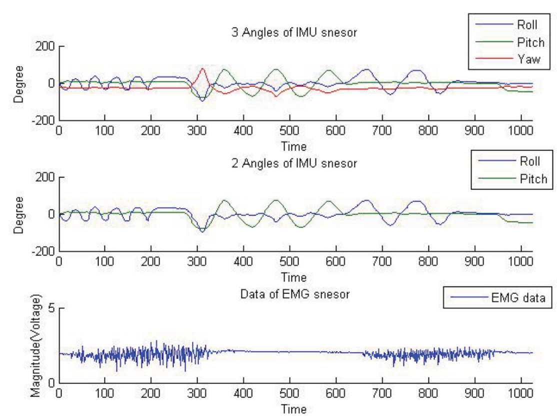

Fig. 6. IMU sensor results

Fig. 6 shows the results of 3-axis IMU sensor value (top), the results that removed the yaw-axis value (middle), and the raw data of EMG sensor represented in voltage (bottom) in real-time. As shown in Fig. 6, the status of IMU sensor measured at every 10 millisecond was presented when the arm force is greater than the threshold value. According to the roll and pitch values, the gesture state was divided into five as shown in Fig. 1.

TABLE I. COUNT OF IMU STATES

Act	Count	Try
RT (Right Turn)	141	3
LT (Left Turn)	224	5
FW (Forward)	284	10
BW (Backward)	167	8
Ready	208	18
Total	1024	44

In Table I, ‘Count’ represents the number that counts the state of IMU each time, where ‘Try’ represents the number that resulted in a continuous count of each gesture. ‘Ready’ in Table I represents the gesture when the palm was facing the floor while the arm was bent at 90 degrees without twisting the wrist immediately before the angular values of roll and pitch were changed from the IMU sensor. Note that in ‘Ready’ gesture, there exists a point where both the roll and pitch of IMU are continuously and simultaneously from zero. Since there is confusion in the command signal and the accuracy of gesture recognition drops in this case, ‘Ready’ gesture was implemented to act as the calibration process. In other words, ‘Ready’ gesture represents the reference point of all gestures in Fig. 1.

IV. CONCLUSION

This paper proposed the independent and continuous gesture recognition system using IMU sensor and EMG sensor. According to the reference point of the EMG signal power, user could control the mobile robot using a series of gestures.

In order to enhance the accuracy of gesture recognition rate when the series of gestures are taken, applying 2-stage HMM in [5] is left as a further work. 2-state HMM will be used in the gesture classification step to improve the gesture recognition rate and its rate will be compared and evaluated to the subject of using HMM.

ACKNOWLEDGEMENT

This research was supported by Technology Innovation Program of the Knowledge economy (No. 10041834, 10045351) funded by the Ministry of Knowledge Economy (MKE, Korea) and Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (No. 2012R1A1A2043822)

REFERENCES

[1] Mitra, Sushmita, and Tinku Acharya. "Gesture recognition: A survey." *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on* Vol 37, No.3, pp. 311-324, May, 2007

[2] Kim, Jong-Sung, Hyuk Jeong, and Wookho Son. "A new means of HCI: EMG-mouse." *Systems, Man and Cybernetics, 2004 IEEE International Conference on*. Vol. 1. IEEE, October, 2004.

[3] Kim, Jonghwa, Stephan Mastnik, and Elisabeth André. "EMG-based hand gesture recognition for realtime biosignal interfacing." *Proceedings of the 13th international conference on Intelligent user interfaces*. ACM, pp. 30-39, January, 2008.

[4] Xu Zhang, Xiang Chen, Yun Li, Vuokko Lantz, Kongqiao Wang and Jihai Yang, “A framework for hand gesture recognition based on accelerometer and EMG sensors”, IEEE Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans, vol.41, Issue 6, pp. 1064-1076, November, 2011

[5] N Nguyen-Duc-Thanh, “Two-stage Hidden Markov Model in Gesture Recognition for Human Robot Interaction.,” *International Journal of Advanced Robotic Systems,* vol. 9, p. 1-10, July, 2012.

[6] Hye Sun Park et al., “HMM-Based Gesture Recognition for Robot Control”, *IbPRIA 2005*, LNCS 3522, pp. 607–614,June, 2005

[7] Moon, Inhyuk, et al. "Intelligent robotic wheelchair with EMG-, gesture-, and voice-based interfaces." *Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on*. Vol. 4. pp. 3453-3458, October, 2003