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Tele-operation between Human and Robot Arm using Wearable Electronic Device

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Abstract: In this paper, a wearable-type motion capturing system is designed and implemented. The device consists of flex sensors, photo detector and luminous element, AVR microcontroller and Bluetooth modules. It can transmit the motion capture data to host computer and then the computer calculates desired degrees for operating the slave robot. As a counterpart of the wearable system, it could be easily wearable, portable and is built to send the human motion data wirelessly. And it has no limitation to detect the human motion because the device capture human's motion directly unlikely motion capture camera using markers which isn't able to detect to their the locations frequently. The proposed system through the wearable device to control the robot arms can show feasible application of wireless man-machine interface and can be applicable various types.

1. INTRODUCTION

Recently, research of robot application like interface between human and machine has been developed and studied as various types over the years. Humans want that machines are more intelligent to serve them in their living life and they also want to control the machines remotely and safely such as TV or appliances. So interfaces between human and machine, including object recognition, motion tracking and capturing, portable haptic, tele-operation, robot vision and even emotion communication method, are focused by robot researchers.

Human motion capturing system, one of the man-machine interface study branch, has been implemented to apply to robot which moves along human motion. It is applicable to robot for dangerous or inaccessible space instead of human by tele-operation with haptic device. A representative motion capturing device is the vision system recognizing markers, exoskeleton type system, device using gyro or acceleration sensors, etc. These systems are probable that have environmental or hardware limitations and cost a great deal to operate. Also they are too heavy or difficult to capture motion for operator. Because of these disadvantages, they have restricted the range of applications, several recently research has been reporting wearable device or material to solve them.(Taro MAEDA) For instance, there are electronic textiles using piezoelectric materials, wearable computing device and haptic system for robot control. (Joshua Edmison)

This study was conducted to propose tele-operation system using wearable motion capture system with Bluetooth module. In order to measure how flexed the joint of elbow and wrist, flex sensors were used. The flexion voltage signals are converted digital signals and transmitted wirelessly by AVR microprocessor with Bluetooth to host computer. The computer receives the signals from the serial port and calibrates them from the sensor's voltage to the joint degrees. To tele-operate the slave robot, the host opens the network connection and transmit the desired joint degrees to the robot. The robot which is used in this study of study is the humanoid robot named MAHRU, developed in Korea Institute of Science and Technology (KIST). When the slave robot receives the desired degrees of the joint, it will generate the motions and move along them.

As the study of man-machine interface based on motion capture device of wearable type, this paper verified possibility of the device by capturing data analysis, simulation and experiments, and could grasped problems or weak points of this study by actually applied for the system using the humanoid robot.

2. CONFIGURATION OF THE PROPOSED SYSTEM

The main goal of the proposed system is to allow the operator to control the necessary or desired motions of robot without the high cost motion capturing cameras or the exoskeleton type's machine.

On the next page Fig. 1, the proposed wearable motion capturing system is showed. The system includes a motion capturing control board, which is consisted of a microcontroller, Bluetooth module and interface board, a rack of a 9 voltage source battery, and two bands mounted a photo detector and a luminous element, wrist protection glove and a elbow protection band implanting flex sensors in.

After the system transfers the sensor's data, the host computer receives and processes the data to desired degrees and then prepares to connect with a slave robot. As connected with the robot, the host computer commands to

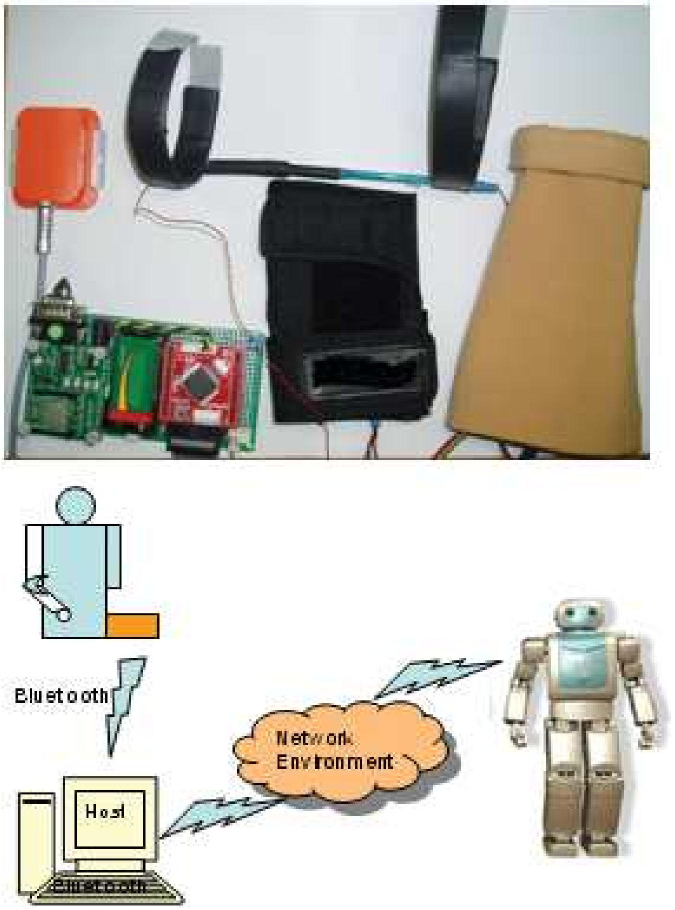

Fig. 1. Overview of the proposed system

robot to ready to remote operation. If the robot is ready to operate, the host computer sends continuously the motion data from the wearable system to slave robot. The slave robot is operated following the motion for receiving data.

3. PROTOTYPE OF THE WEARABLE SYSTEM

3.1 Flex Sensor

To measure wrist and elbow motion's degrees, this study used flex sensors. The characteristic of these sensors changes themselves the resistance when they are bent or strained.

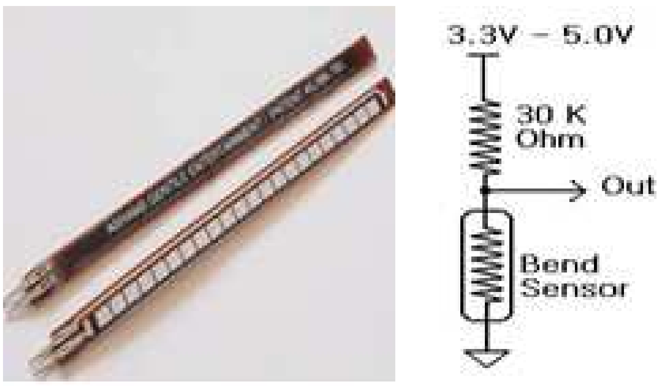

Fig. 2. A flex sensor and simple circuit

The resistance range of the sensor is that nominal resistance at 0 degrees is 10,000 ohms and at 90 degrees 35,000 ohms. On the Fig. 2 is a flex sensor and simple circuit.

3.2 Photo detector and Luminous element

The photo detector and luminous element are used to measure the yaw axis between wrist and elbow. The photo detector attached at wrist senses the light intensity from luminous element. The gap of them is changed when the wrist rotates and then the photo detector's output voltage also changed ,so we could calibrate the wrist yaw motion's degrees.

3.3 Micro-controller

To convert the analog data to digital from the flex sensors and the photo detector, we built a customized control board. To develop the control board we used an ATmega128, an 8 bit microcontroller from Atmel Inc. The microcontroller has an 8 channel, 10 bit A/D converter and dual programmable Serial USARTs which connects with Bluetooth serial interface.

3.4 Bluetooth

To transfer the converted data from the microcontroller to master computer, we installed the embedded Bluetooth module, FB155BC from Firmtech Inc. The module has up to 30 meters RF range and small dimension (18 x 20 mm). It connects with the microcontroller's serial interface for transferring converted sensors data to host computer.

3.5 Inertia Measurement Unit

In this study, the inertia measurement unit(IMU) is used to measure of joint motion angle in the host computer. To calibrate voltage of the flex sensors and photo detector via degree, the IMU is only operated after had on when the wearable system. As once calibrated to degrees by the IMU from the received voltage of each joint sensor's initial position to continuously changed voltage value about its position moved variously, the host computer is able to manage the sensor's voltages as degrees. To experiment this paper, it is used for the IMU from Xsens Technologies B.V. that is miniature IMU with integrated 3D magnetometers, with an embedded processor capable of calculating roll, pitch and yaw in real time.

4. SLAVE ROBOT

To Show the operation of this system, we used the humanoid robot named MAHRU as the target slave robot. The robot was developed as platform for the research of the network based humanoid. It has 6 DOF for each arm and leg, 1 DOF for waist, 2 DOF for neck and 4 DOF for each hand.(Kim, D.I.)

For real-time implementation, the Linux kernel with Xenomai was installed in the robot controller computer. Xenomai is a real-time development framework cooperating with the Linux Kernel. It is free software and it guarantees hard real-time to user-space application. Fig. 3

shows the humanoid robot, Mahru and its right arm DOF. And Table 1. is showed the D-H parameters.

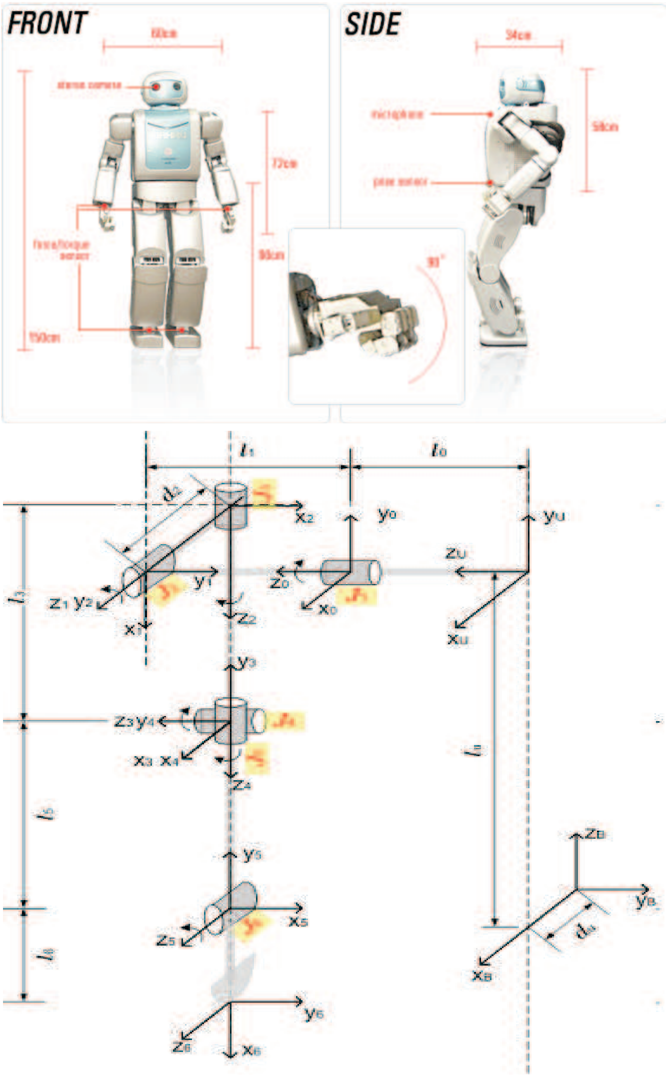

Fig. 3. The Humanoid robot and right arm DOF

Table 1. **The right arm D-H parameters**

Link	θ_i	d_i	a_i	α_i	θ_{i0}
$B-U$	0	l_u	d_u	$\pi/2$	0
$U-J_1$	0	$-l_0$	0	0	0
L_1	ϕ_1	$-l_1$	0	$-\pi/2$	$-\pi/2$
L_2	ϕ_2	d_2	0	$\pi/2$	$\pi/2$
L_3	ϕ_3	l_3	0	$-\pi/2$	$\pi/2$
L_4	ϕ_4	0	0	$\pi/2$	0
L_5	ϕ_5	l_5	0	$-\pi/2$	$-\pi/2$
L_6	ϕ_6	0	l_6	0	$-\pi/2$

5. EXPERIMENTS

5.1 Finding Approximation model method for the sensors

To make an algorithm for converting from sensor's voltage to degree, the sensors are tested about their hysteresis. Fig. 4 shows the hysteresis of the flex sensors. This graph was obtained by bending the sensor like human's joint angle using IMU. Based on the result of hysteresis test, the approximation model was found by curve fitting of the 3rd order polynomials. In order to minimize the standard deviation of root mean square error, the polynomial coefficients is calculated by equation (1). (R.T. Haftka) The found model is showed Fig. 5

$$y = \hat{y} + \varepsilon$$

where $\hat{y}$ is approximation model, ε is error.

$$\hat{y} = \sum_{i=1}^{n_\beta} \beta_i \xi_i(x)$$

Difference between the model and j_{th} experiment

$$e_j = y_j - \sum_{i=1}^{n_\beta} \beta_i \xi_i(x)$$

In vector form e = y - Xb
rms error

$$e_{rms} = \sqrt{\frac{1}{n_y}\sum_{i=1}^{n_y} e_i^2} = \sqrt{\frac{1}{n_y} e^T e}$$

So that minimizing e_{rms} is equivalent to minimizing $e^T e$

$$\begin{aligned} e^T e &= (y - Xb)^T (y - Xb) \\ &= y^T y - y^T X b - b^T X y + b^T X^T X b \end{aligned}$$

To find vector b that minimizes e_{rms},

we differentiate $e^T e$ with respect to the components of b and set the derivatives to zero.

$$X^T X b = X^T y$$
$$b = (X^T X)^{-1} X^T y$$

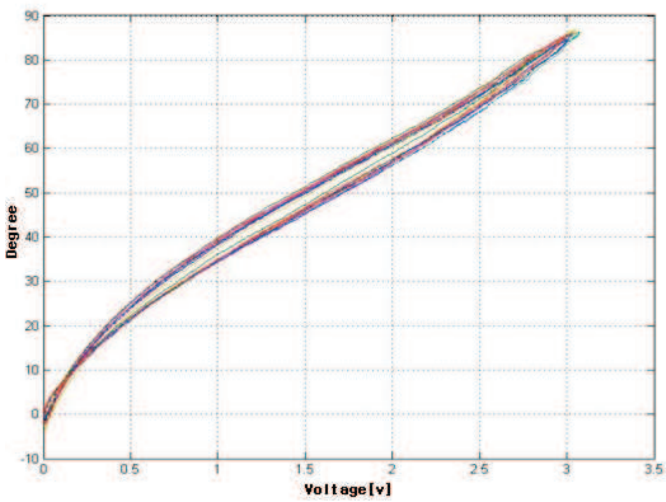

Fig. 4. Hysteresis of the flex sensor

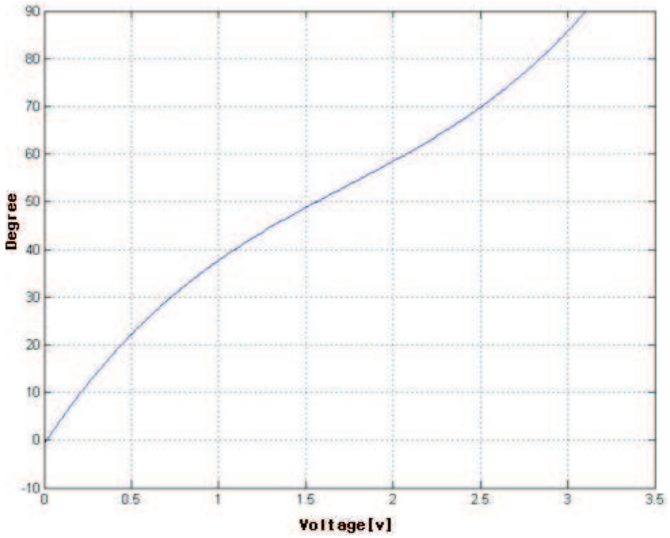

Fig. 5. The result of Approximation Model

5.2 Calibration with Approximation Model

To calibrate angle of each joint, it needs for the operator to make approximation model about each joint at first one time. Top and middle graph Y axis means degrees and X axis means computer tick(frame) that 10 ticks are one second(10Hz). And the bottom graph 's Y axis means degree and X axis means voltage, so it is the calculated approximation model. Top graph is degree from the IMU and middle is the voltage output of the flex sensor mounted the elbow bands. Two graphs already have been filtered by a running average filter with size of 5 windows. The graphs are both represented original and filtered signal. The dot line is the original signal and The line is filtered signal. Fig. 6 shows the plot of the elbow calibration and the approximation model and Fig.7 is the plot of the wrist yaw axis calibration and the model. Also Fig. 8 is represented the graph of wrist roll axis calibration and the model.

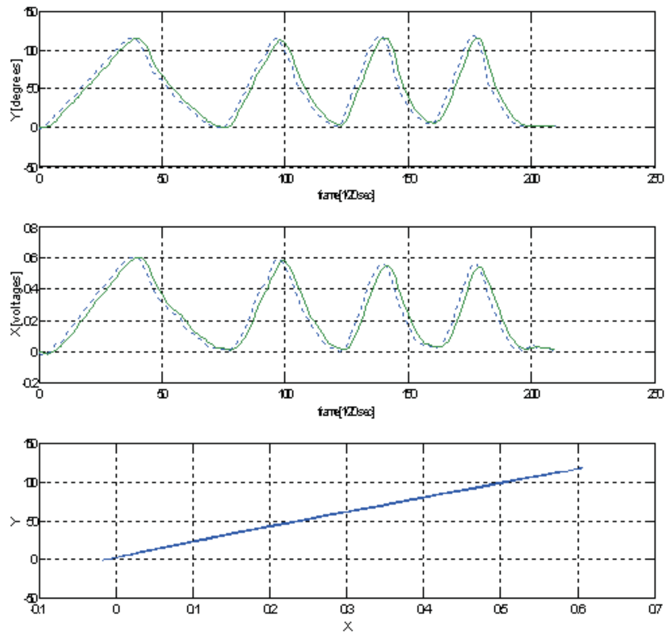

Fig. 6. The elbow angle's Approximation Model

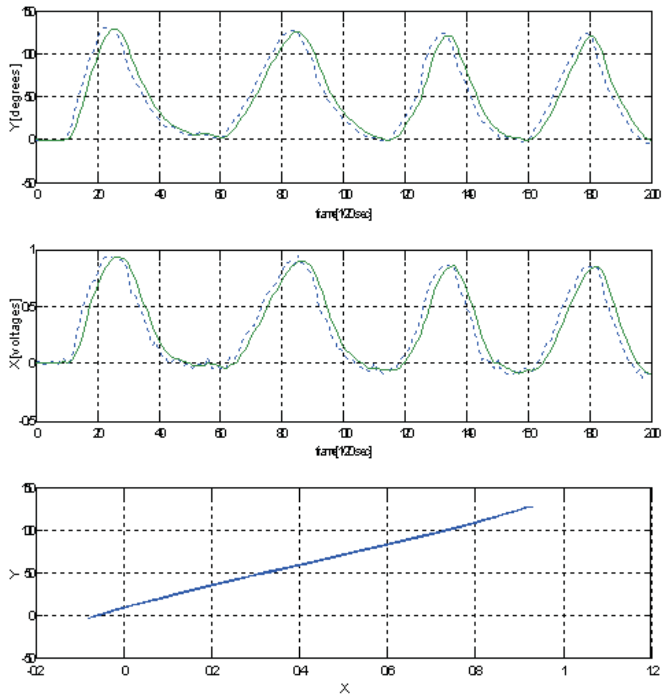

Fig. 7. The wrist yaw angle's Approximation Model

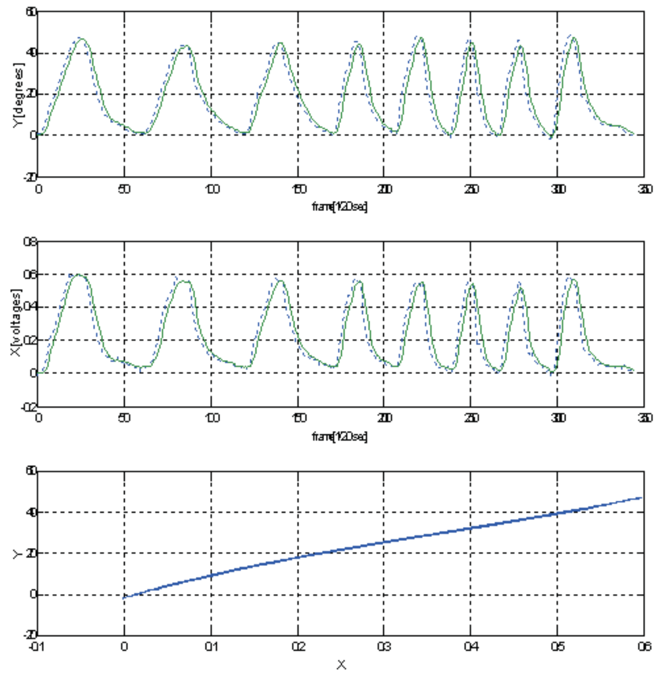

Fig. 8. The wrist yaw angle's Approximation Model

5.3 Tele-Operation

After calibrated the wearable systems, the host computer connects with the slave robot. The slave robot is ready to move following the transferred motions. In the robot, the interface for humanoid controller is able to make trajectories of desired joint position in real-time, so the robot starts to move along tele-operator's motion. Fig. 9 shows the experiment. To verify the performance of the proposed system, tele-operator who wear the system

Fig. 9. Experiment for humanoid robot

conducted the various arm motion. Figures 10, 11 and 12 show the angle about desired positions which is the dot line and actually moved positions, which is the line, of each joint and the error value of between desired and real angle. All graphs' X axis mean computer ticks (200Hz) and All's Y axis mean degrees. The main reason of error is that the interface humanoid controller module in the robot is planning for robot motion. If the planning is wrong or mismatched with robot structure, the module is re-planning about the motion.

6. CONCLUSIONS

This paper proposes a wearable tele-operation system and explains the implementation of the prototype. We conducted experiments using the humanoid robot MAHRU as a slave robot to confirm the proposed system performance.

Through these tele-operation experiments, We successfully demonstrated arm motion capturing and mimicking via network environments.

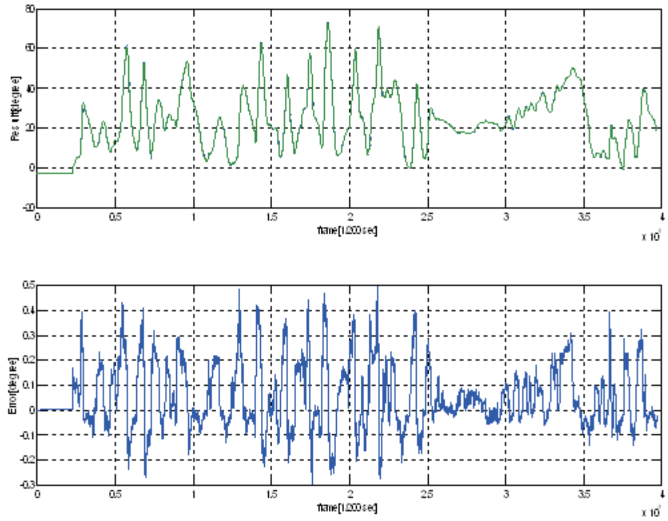

Fig. 10. the elbow Joint Trajectory & errors

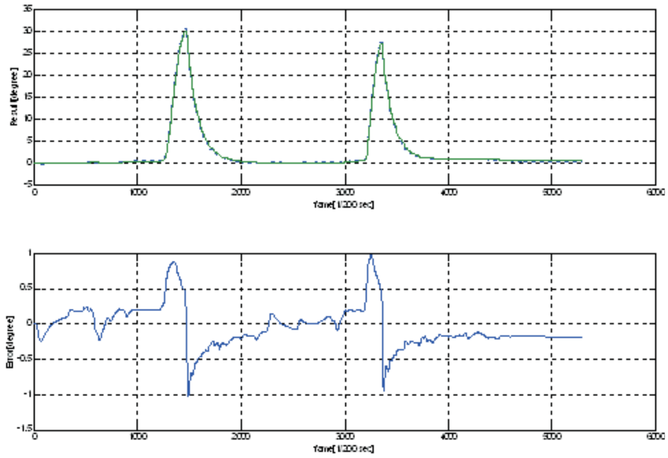

Fig. 11. The wrist yaw Trajectory & errors

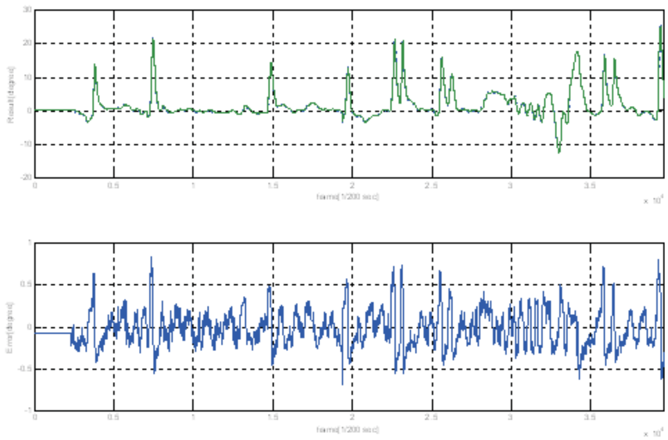

Fig. 12. The wrist roll Trajectory & errors

In the future work, we will implement to expand shoulder joint and hand motion using force glove and then prove the performance by experiments with the robot. And to enhance the master system, we will research compensation algorithm for interference with joints each other.

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