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Smart Glove for Augmented and Virtual Reality

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ABSTRACT

This research work is carried out on designing and prototyping a smart glove, which can conduct 3D interaction with computer MATLAB model in real time. The smart glove is constructed with only inertial measurement units for gathering and achieving human hand movement position data. This application will support the accuracy of the device and provide additional flexibilities for human interaction with other objects. The purpose of our design is to provide a smart glove with low price (less than 100€) for researchers in different institutions to develop their research projects with virtual and augmented reality. The design of hardware and software, as well as prototyping experiments is also presented.

Keywords: Smart glove; augmented reality; gyroscope; accelerometer; virtual reality; Matlab Simulink; complementary filter.

1. INTRODUCTION

Smart gloves have real potential for human-machine interfaces and interactions. In the future, they can replace the usual mouse, keyboard and joysticks. Smart haptic gloves can offer more intuitive interface since they are using 3D movements in space. 3D movement is better to detect the human intentions and provides more accurate prediction in natural interaction environments.

Virtual reality becomes an industry in which technologies evolve at the same time with the applications. For example, if there is virtual reality helmet or glasses, there must be applications for them to interact and to operate. That is why the applications for virtual reality are rapidly covering all fields: Movies; Games; Online streams; Social networks; Medicine; Education; Trading; Manufacturing; and Engineering.

A survey on environments and system types of virtual reality technology in science, technology, engineering, and mathematics fields presents in [1]. It introduces detail information on virtual reality systems and makes comparison among them. Another review on immersive environments and virtual in [2] provides latest advances in communication and simulation in virtual reality world. A review on general concept and application of virtual reality haptic technology is briefed in [3]. This paper summarizes latest experimental publications, available studies and development of research projects in haptic virtual reality system.

Related to application of haptic glove on remote control, a tele-operation system, paper in [4] presents a novel scheme for a tele-operation system in variant time delays and environment uncertainties. The system can be used for a medical doctor examining remote patients. Reference in [5] presents state of the art in haptic devices to improve interactions of tools applied in the evaluation of product design.

A project in [6] introduces a passive deformable haptic glove to support 3D interaction in mobile augmented reality environments. The glove is designed with a digital foam sensor placed under the palm to support precise direct touch manipulation. Paper in [7] presents haptic links as electro-mechanically actuated physical connections that can improve the haptic rendering of two-handed objects and interactions in virtual reality.

Most of above haptic gloves are with high cost and based on flex sensors, which change their resistance by bending. These sensors are expensive and cannot register resistance change in several bending points. One low cost sensor glove with vibrio tactile feedback and multiple finger joint and hand motion sensing for human-robot interaction presents in [8]. This low-cost glove is made with price of 300€. Another low-cost sensor glove with force feedback for learning form demonstrations using probabilistic trajectory representations introduces in [9]. This glove is fabricated with price of 250€. Updated references are referred to in [10], [11], [12], [13], [14], [15], [16], [17], and [18].

In our research work, a low-cost glove for real time interaction with virtual robot arm is designed with price of less 100€. That enables researchers in different institutions to develop their applied research project with virtual and augmented reality software in various applications.

2. GLOVE DESIGN

Based on anatomical and medical hand analysis, the hand skeleton model has 23 degrees of freedom (DOFs) as shown in Figure 1.

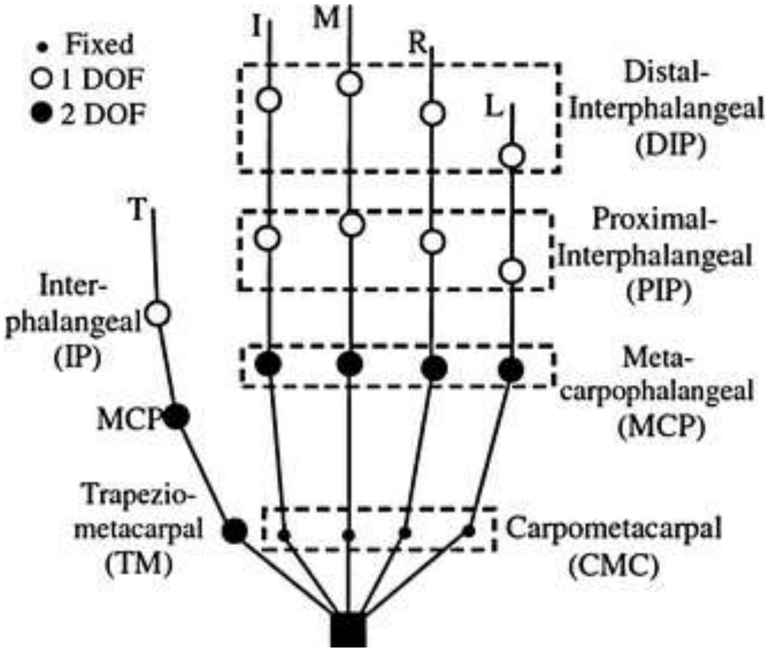

Figure 1. Human hand model

Each of the four fingers has four DOFs. The Distal-Interphalangeal (DIP) and Proximal-Interphalangeal (PIP) joints both have one DOF, and the remaining two DOFs are located at the Meta-Carpophalangeal (MCP) joint. Different from the four fingers, the thumb has five DOFs. Two DOFs are at the Trapeziometacarpal (TM) joint, also referred to as the Carpometacarpal joint (CMC), and two are at the MCP joint. The remaining one DOF of the thumb is at the Inter-phalangeal (IP) joint. The basic flexion/extension (F/E) and abduction/adduction (Ab/Ad) of the thumb and fingers are performed by the articulation of the 21 DOFs. As shown in Figure 2, the F/E motions are used to describe rotations toward and away from the palm, which occur at every joint within the hand. The abduction is the movement of separation (e.g., spreading fingers apart), and the adduction motion is the movement of approximation (e.g., folding fingers together). The Ab/Ad only occurs at each finger's MCP joint and at the thumb's MCP and TM joints. Another two internal DOFs are at the base of the fourth and fifth (ring and little finger) metacarpals, which perform the curve or fold actions of the palm.

In our glove, each IMU MPU-6050 device has 2 different addresses and a multiplexer 74HC4067 is used. This multiplexer can be controlled by microcontroller STM32, which will send registers to 4 multiplexer inputs and reads data sequentially from it. Then, the microcontroller gathers data and sends data package to computer over DMA USART communication protocol. The DMA USART can be used in several ways. For example, the microcontroller can be connected directly via TTL-USB converter or distantly via Bluetooth module. After receiving from sensors and processing in microcontroller, data is used to calculate the real angle movement. The control system diagram is shown in Figure 3 of the next section. Then, a glove prototype is fabricated and shown in Figure 2.

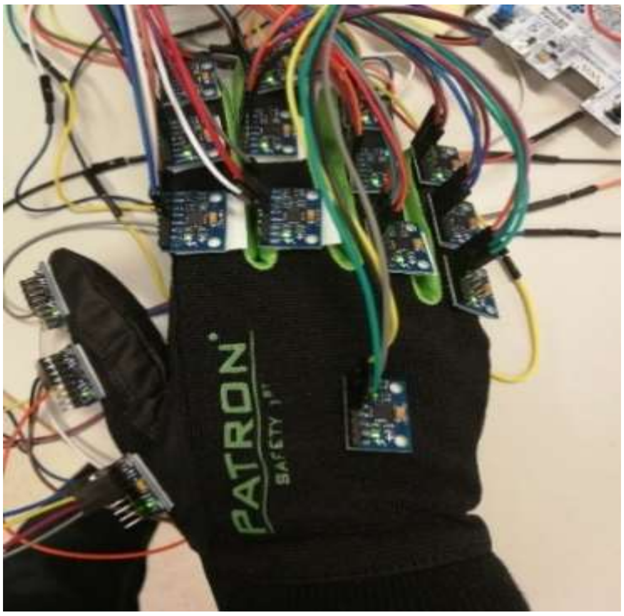

Figure 2. Glove prototype with 16 MPU-6050

3. ANGLE CALCULATION AND DATA COLLECTION

In the initial position, when the gravity force acts only in the opposite direction along the *z* axis, it is seen that all angles are equal to 0. From the properties of the sine and cosine that while the sensitivity along one axis decreases, it increases on the other. The rotation angles around axis *x*, *y*, and *z* can be detected in the accelerometer sensors and calculated by the following formulas:

$$\alpha = \arctan\left(\frac{A_x}{A_z}\right) \tag{1}$$

$$\beta = \arctan\left(\frac{A_y}{A_z}\right) \tag{2}$$

$$\gamma = \arctan\left(\frac{A_y}{A_x}\right) \tag{3}$$

where A_x – gravity force vector along *x* axis, g, A_y – gravity force vector along y axis, g, A_z – gravity force vector along *z* axis, g.

The rotating angles can be also detected from the gyroscope sensors. The gyroscope provides not the acceleration and not the angle, but the angular velocity. Therefore, it is less sensitive to noises and vibrations. To obtain the angle from the angular velocity, the gyroscope data must be integrated and an initial angle (i.e., zero angle of the gyroscope) added to the output angles. Integration is performed following the algorithm:

$$\alpha(t) = \alpha(t-1) + \text{rawData} * dt \tag{4}$$

where, $\alpha(t)$ - current angle at time (t), deg, $\alpha(t-1)$ - angle at the previous time period, deg, rawData - raw data from the accelerometer, deg/ms, dt – step time, ms.

A complementary filter is built using the combination of two data from gyroscope and accelerometer. The following algorithm is used for the complementary filter:

$$\theta_{filtered} = FK * \theta_{accel}(t) + (FK-1) * \theta_{gyro}(t-1) \tag{5}$$

where θ_{accel} – angle from the accelerometer, deg, θ_{gyro} – angle from the gyroscope, deg, $\theta_{filtered}$ – filtered angle, deg, FK – complementary filter coefficient can be adjusted from 0 to 1.

The filter data is tested in a stable position. As a result, in Figure 3, the filtered data looks smoother and less vibrated than the data from the accelerometer. Next, this filtered data is tested with a real dynamic movement.

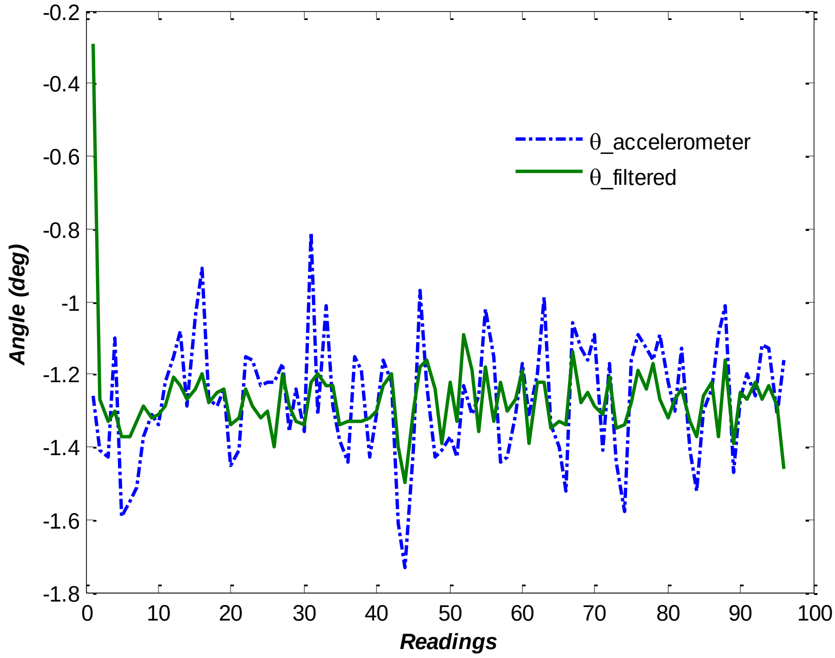

Figure 3. Filtered vs accelerometer data in a static position

The filtered data is now tested with the arm moving from +90 degrees to -90 degrees. Figure 4 shows that the filtered data is better than accelerometer data.

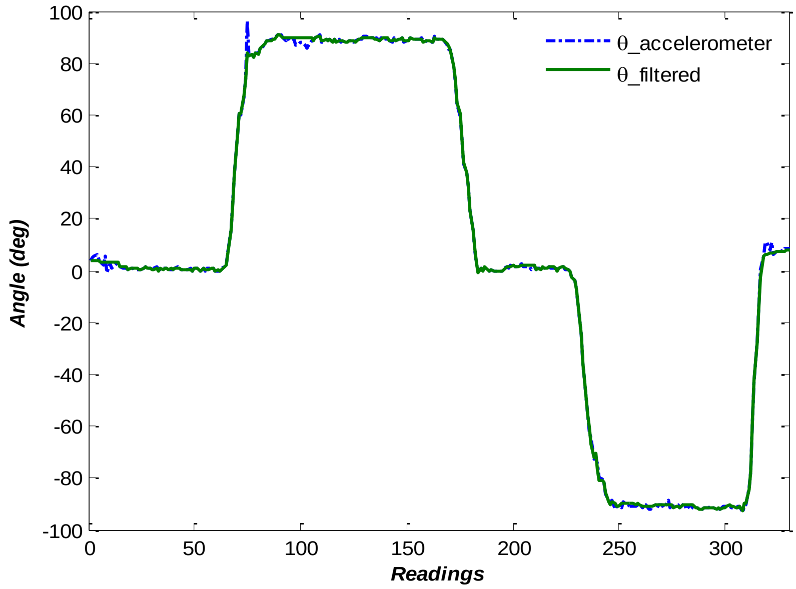

Figure 4. Filtered vs accelerometer data in a dynamic movement

4. MATLAB SIMULATIONS AND EXPERIMENTAL RESULTS

For the visualization of the prototype, it is needed to design a simulation in appropriate software. In this study, Matlab Simulink is selected since it is possible to build physical components in Simulink environment and implement receiving data from Simscape add-on blocks. A 3D solid-work arm is designed and transferred into Matlab Simscape. Figure 5 shows the 3D solid-work arm model is working in Matlab with full elements of hand, fingers, elbow and wrist.

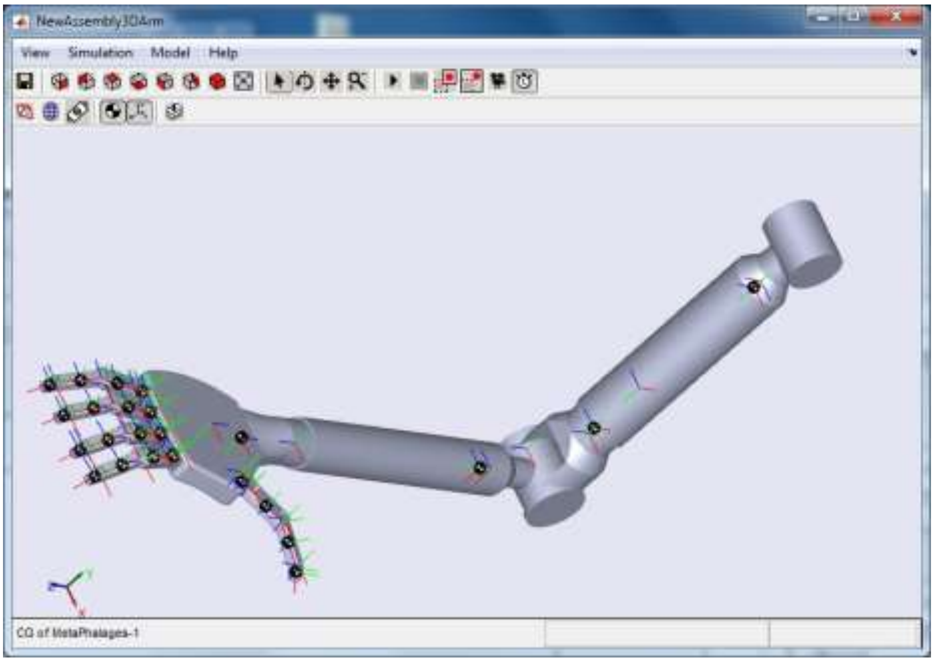

Figure 5. 3D solid work arm design

The glove prototype with all sensors, microprocessor and communication system is fabricated. As mentioned earlier that the aim of this project is to design a low-cost haptic glove. At this final step, the total expensive for the prototype is less than 100€. The cost analysis is shown in Table 1.

Table 1. Cost Analysis

Items	Details	Unit Cost	Quantity	Cost
3-Axis Gyroscope/Accelerometer	Tracking hand movement	0,82 €	16	13,12 €
Vibration Motors	Variable speed, multiple operating voltages	0,30 €	24	7,20 €
Battery	Lithium Polymer 3,6V	8,50 €	1	8,50 €
Bluetooth USB	USB receiver	3,03 €	1	3,03 €
Bluetooth Module	Communicates with dongle and microcontroller	1,74 €	1	1,74 €
STM32 F413ZH	Data proceeding	16,00 €	1	16,00 €
Glove	One size glove	3,00 €	1	3,00 €
PWM Module	Drives motors	2,75 €	1	2,75 €
DC-DC converter	Converts current	3,50 €	1	3,50 €
Charger	Allows to charge	1,30 €	1	1,30 €

	battery using USB port			
Multiplexer	Multiplex signals	4,00 €	1	4,00 €
Software	All used software in the project and its cost	-	-	-
Shipping	Cost to ship all parts	-	-	11,82 €
			Total:	**75,96 €**

The followings are some experimental results of rotating angle data recorded from the arm, index finger and middle finger. This data is calculated as reference paths and control the virtual robot tracking exactly on those paths in real-time by a PID controller. Figure 6 shows the rotating angle of the arm around axis *x*, *y*, *and z.*

In addition, a testing video is recorded and shows that the prototype works correctly and correspondingly to the hand movement in real-time. The YouTube video can be seen at the link: https://www.youtube.com/watch?v=hRFgJV7qrsU.

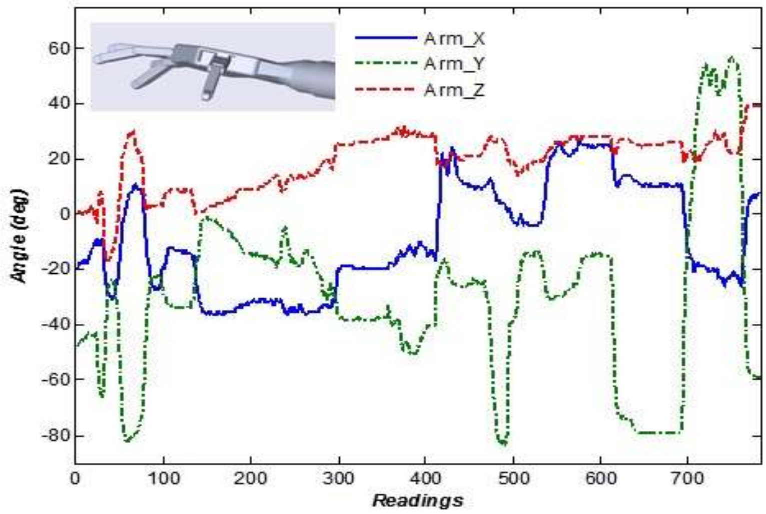

Figure 6. Arm rotation around *X*, *Y*, *and Z* axis

5. CONCLUSION

This haptic glove can provide 23 degrees of freedom and correspond to a real human arm. The haptic glove can fit also with different people hands. Simulations show that the glove can provide accurate angular movement of arm, joints and control correctly in real time the movement of a virtual robot in PC. The cost for this haptic glove is less than 100€. Applications of this haptic glove can be applied for simulating a virtual robot or for remotely controlling a real robot arm. In the future, the prototype can be installed with MEMS sensors to improve the speeds and accuracies of the angular detections. In the future research work, the 3D solid work arm can be re-designed more sophisticatedly and corresponding better to the human real hand.

CONFLICT OF INTEREST

The authors confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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