Application Development for a Gesture Capture Glove Based on Accelerometers and Gyroscopes

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***Abstract*—The wide adoption of portable devices by the population in the entire world, such as smartphones and tablets, requires the development of efficient input devices. We developed a glove capable to capture hand movement in a three-dimensional space and convert it into digital data. This paper describes some applications using this new human-computer interface. It can be used as a pointing device, where it is possible to move remotely the computer cursor with the index finger movement, as a keyboard device, for typing on computers and smartphones. It is also possible to use it as a joystick, to control game characters, or as a virtual 3D hand, for simulating movements and for remote control. All applications demonstrate the full glove capability, which provides agility and improves efficiency in human-computer interaction.**

I. Introduction

Electronic portable devices, such as smartphones, smartwatches and tablets, are becoming increasingly popular among the entire planet. These devices make peoples everyday lives easier, and they are fundamental in the development of new applications. However, because of the reduced size, the interaction between human and machine is difficult, especially typing on small virtual keyboards. Besides uncomfortable, the interaction can cause physical damage to the body - such as repetitive strain injury and tendonitis - if used by a long period. Thus, it is necessary to develop new interfaces that allow a more agile human-computer interaction with less effort to the user.

Some strategies for substituting traditional keyboard, mouse and joystick were reported in the literature, like a glove-based device [1], a vision-based device [2], a depth based device [3] or a combination of them into a single device [4].

For dealing with this problem, we developed in our group a gesture detection glove capable of recognizing patterns of hand movement and transform them into digital information [5]. The proposed system consists of six accelerometers and six gyroscopes located at the fingertips and over the posterior part of the hand, allowing precise detection of movements in three-dimensional space. The sensors are read by a microcontroller, implemented in an FPGA over the glove, which processes the values of linear and angular acceleration and sends the information to the final device (a computer, a smartphone or a tablet) by Bluetooth communication protocol. Fig. 1 shows the prototype of the implemented system.

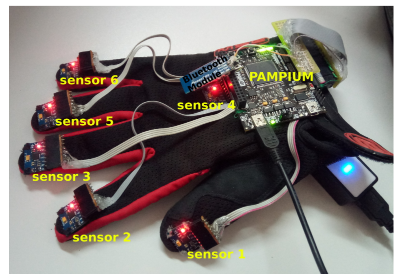

Fig. 1. The glove prototype.

The developed glove opens the possibility to the development of many applications, such as the recognition of movement patterns of sign languages for writing on digital equipments. It allows people with some kind of special needs (blind or deaf-mute, for example) to interact more efficiently with a computer. The glove may replace conventional joysticks and mice devices with the advantage of inserting more degrees of freedom to the control. Another uses can also be cited, such as digital game control, virtual reality interface, motion detection for physiotherapy exercises, training for health academics and remote control of robots. Also, the glove may be used as a platform for teaching activities through the development of applications that can exploit its functionalities. The goal of this paper is to describe the implementation of some of these applications.

II. Interface driver

We implemented an interface driver for reading and processing the glove data by a computer (final device) in Java language. This interface receives accelerometers and gyroscopes data from the glove through Bluetooth and processes the information according to the application. A pre-treatment of the data is necessary for noise suppression and rotation detection. Sensor data are normalized to a range of -10 to +10 for the accelerometers and from $-\pi$ to $+\pi$ for the gyroscopes. The gyroscopes identify the angles of rotation of the sensors in relation to a reference. Thus, we need to correct the accelerometer values in the X, Y and Z local axes for the fixed x, y and z axes of the application. The start position of the sensors is used as reference for the correction of the movement in relation to the values read from the sensors. The hand must

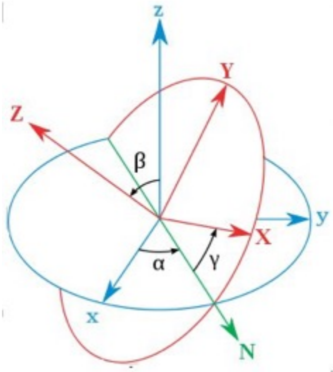

Fig. 2. Rotation in 3-D space.

start in the horizontal position in order to the driver identify the amount of adjust necessary for the exact location of the sensors in relation to the application reference. Therefore, if the sensor is tilted relative to the external reference, the acceleration must be adjusted for each axis. Fig. 2 shows the intrinsic rotation of the sensor axes to the fixed coordinate system of the application space. The angles α, β and γ represent the Euler angles that can be calculated with the values obtained by the gyroscopes.

To identify the coordinates of the vector in the application axes in a 3-dimensional space we use the following rotation matrices:

$$R_x(\gamma) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos(\gamma) & -sin(\gamma) \\ 0 & sin(\gamma) & cos(\gamma) \end{bmatrix}$$
$$R_y(\beta) = \begin{bmatrix} cos(\beta) & 0 & sin(\beta) \\ 0 & 1 & 0 \\ -sin(\beta) & 0 & cos(\beta) \end{bmatrix} \quad (1)$$
$$R_z(\alpha) = \begin{bmatrix} cos(\alpha) & -sin(\alpha) & 0 \\ sin(\alpha) & cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The product of the rotation matrices produces the complete rotation of a given point:

$$R = R_z(\alpha) \cdot R_y(\beta) \cdot R_x(\gamma) \quad (2)$$

Thus, we calculate the new coordinates P' of a point P as:

$$P' = R \cdot P \quad (3)$$

To eliminate noise and outliers, we use a moving average low pass filter over the data read from the sensors. In this filter, each point is replaced by the arithmetic mean of its n neighbor points. The higher this value, the higher the degree of smoothing. In this design we use an arbitrary $n = 11$.

III. Applications

With the implemented glove prototype it is possible to implement several applications that use the gesture capture glove as an interface device, such as keyboard and pointing device, sign language interpreter, virtual reality control, etc. This section describes some of the implemented applications.

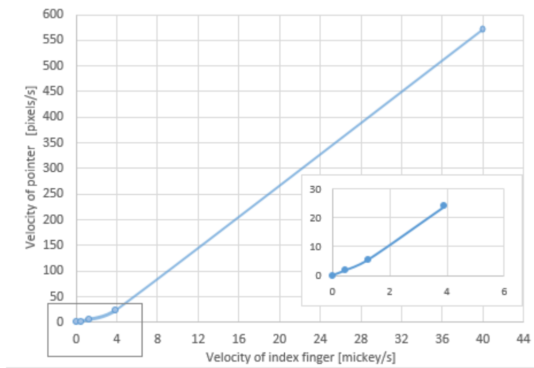

Fig. 3. Transfer function relating the velocity of index finger and the velocity of screen pointer.

A. Glove as a pointing device

A direct application of the gesture capture glove is the control of the cursor movement in a computer. It is the simplest application, but it demonstrates the capability of the glove interacting with the machine. In addition, it allows access to any application that has the mouse as a control device.

Cursor movement is controlled by the index finger. The movement in the direction of the x and y axes of the screen (hand in the horizontal position) allows smooth and intuitive control of the mouse cursor. The accelerometer values read from sensor located at the index fingertip, are converted to cursor offset and transmitted to the operating system through the interface implemented in Java. In order to have efficient navigation and pixel level accuracy, we adopt a transfer function as shown in Fig. 3.

The transfer function relates the velocity of the index finger (in arbitrary unit mickey/s) to the actual mouse speed (in pixel/s). It is divided in four regions delimited by five points: (0, 0), (0.45, 1.8), (1.25, 5.5), (3.9, 24), (40, 570). The inclination of the first line segment produces a small physical gain in the screen, allowing precision movements and the ability to reach each pixel on the screen. If the index finger movement is not sufficient to move the pointer one pixel on the screen, this value is stored and added in the next count. The gain is increased for higher speeds, in order to afford a natural movement sensation to large cursor displacement.

Mouse click is implemented moving the index finger down. What differentiates the click movement and cursor movement on the y-axis is the position of the thumb. When stretched, it permits movement of the pointer. When leaning next to the index finger, it freezes the pointer movement and the click is performed if the index finger moves down. The detection of the position of the thumb is easily performed through the z-axis value of the accelerometer located in this finger.

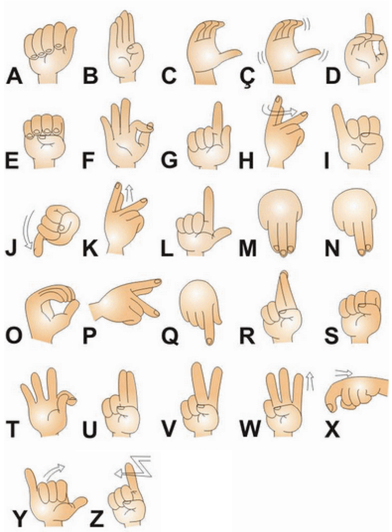

Fig. 4. Gestures corresponding to the letters of the alphabet in the Brazilian signal language (LIBRAS) .

B. Glove as a keyboard

Another application suitable for the developed glove is the recognition of letters from gestures, in which the user makes a certain movement and the application understands it as a key pressed in the keyboard. We adopted the alphabet from the Brazilian signal language (LIBRAS), as shown in Fig. 4, as standard for the gesture recognition. LIBRAS is the official Brazilian signal language and its use is widespread along the country. With the combination of various gestures it is possible to spell complete words and phrases. The automatic recognition of the gestures with the glove and the translation to a letter in the keyboard allows the typing in a portable device (a smartphone, for example) in an easy and intuitive way for a deaf-mute or blind person.

The procedure for identifying the letters of the alphabet is made with the aid of machine learning. The classification algorithms must be trained with samples of known patterns in a supervised learning process. The model resulting from the training process is used to predict the corresponding letter of unknown samples. For supervised learning, we collected 5 repetitions of gestures corresponding to each letter from 2 volunteers. We tested several classification algorithms and the one that provided the best accuracy was the Support Vector Machine (SVM) with the Radial Basis Function kernel (RBF). The design space is divided in 28 classes corresponding to all letters of the alphabet plus the symbols for "space" and "idle". The input data has 18 features, composed of the measurements of six 3-axes gyroscopes previously described, captured from the glove at a given instant.

C. Glove as Joystick

The glove also has applications in the world of digital games. We can control the characters with the hand taking advantage of the cursor movements, as described in section III-A. We implemented a game based on the fruit ninja game

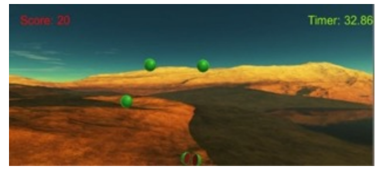

Fig. 5. Example of a game controlled by the glove.

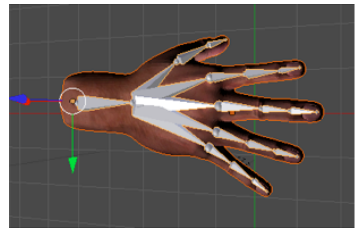

Fig. 6. 3D hand model with bones (in white).

Fig. 7. 3D hand model in Unity Framework.

for demonstrating the usability of the developed glove. The objective of the game is to cut fruits with the character - in this case, the point of the cursor. When the fruit is hit, it appears as cut and the score is increased. The character follows the movement of the index finger. Fig. 5 shows a screenshot of the developed game. The ease of movement allowed by the glove makes the control of the character much more agile and intuitive in comparison to a conventional joystick.

D. 3D Hand Model

The full glove capability can be demonstrated with a hand 3D model. This virtual model reproduces the real hand movement by means of the values read from the accelerometers and gyroscopes. Each finger movement is independent from the others, which provides a realistic control of the 3D model.

The 3D model was implemented in Unity Framework. It is composed of bones for assembling each part of the finger. Fig. 6 shows the figure of the hand model, where the bones are indicated in white. The bones are connected to each other so that the articulations reproduces a realistic hand movement. The fixed reference is located at the wrist.

Fig. 7 shows the rendered virtual 3D hand controlled by the glove in the Unity Framework. Unity is a very popular tool for building games. It makes it easier to work because much of the game scenario is done by dragging and dropping objects. In addition, it provides native methods for the control of the hand bones, which allows the fingers to move a given distance while keeping the hand integrity.

The movement of each finger is calculated by the difference between the current and the previous values read by the related gyroscope. This difference is added to the current position

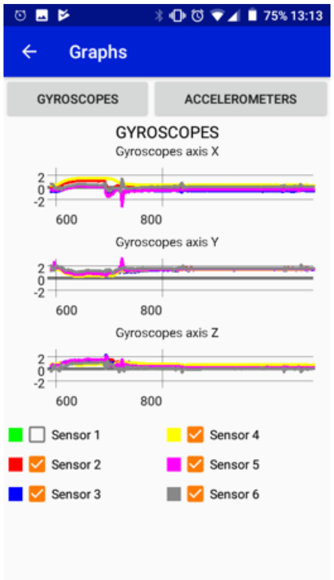

Fig. 8. Graphical visualization of gyroscopes data in the Android smartphone application.

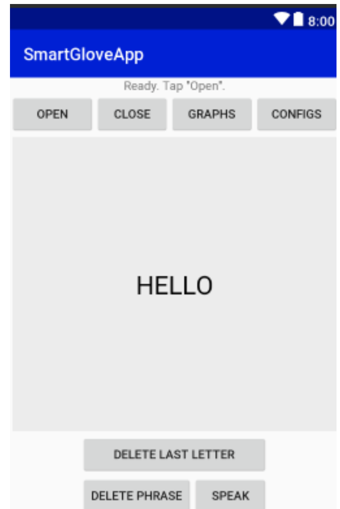

Fig. 9. Gesture identification as a letter of the alphabet in the Android smartphone application.

of the bone at the fingertip. Each finger has three phalanges, except for the thumb, which has two. The position of the bones are estimated in order to give the impression of hand closing or opening. This estimation is made by the multiplication of the bone position by a coefficient of the calculated gyroscope difference. The coefficients were defined as 1.3 for the distal, 1 for the middle and 0.7 for the proximal phalange. The movement of the entire hand is calculated according to the value read from the accelerometer located on the back of the hand. To catch an object, we use a collider as a trigger that is activated when the hand is open and it closes near to an object. The object local axes become child of the hand, and follow the hand movement. When the hand is opened, the object axes stop being a child, causing the hand to release the object.

E. Smarthphone interface

We developed a dedicated smartphone application for the communication with the glove. It allows a practical use of the device, providing full mobility to the user. The application was developed in Android Studio and the communication protocol was adapted to this platform as a running class in Java language. So, the data from the sensors are directly available for any other class.

Two activities were implemented in the application, one for raw data visualization and other for the classification procedure. It is possible to choose the sensors that will be visible. Each sensor has a corresponding color, facilitating the identification in the graph. Fig. 8 shows the corresponding screen for gyroscope data visualization. In this example, it is possible to notice that the data from sensor 1 (green), corresponding to the thumb, is not shown when we uncheck its respective checkbox.

Fig. 9 demonstrates the screen interface for the keyboard prediction mode for Android. The procedure is the same that was described in section III-B, with the same trained model but with the algorithm adapted to smartphone and with the parameters loaded from a text file. The user makes the gesture corresponding to a given letter of the alphabet, the prediction algorithm understands it based on the gyroscopes data and print it on the screen. When a complete word is spelled, the application proceeds a text-to-speech function, thus speaking the word.

IV. Conclusion

The development of applications such as mouse movement, joystick control, sign language character recognition and the 3D model shows the potential of the glove as an input data device, allowing a new way to interact with computers and smarthphones, with a greater immersion experience.

The glove is specially suitable for blind and deaf-mute people to interact with a computer or smartphone in a more efficient way, acting as an interpreter to the sign language, facilitating the communication. The social impact is clear, since the proposed system can mitigate the difficulty of people with physical deficiency in communicating.

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