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Preliminary Study on Wearable System For Multiple Finger Tracking

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Abstract. Devices that track the human body movement are heavily used in numerous and various fields like medicine, automation and entertainment. The work proposed is focused on the design of a modular device able track the flection of human hand phalanxes. The overall system composed by two parts: a computer program interface and a modular wearable system applied to the finger whose motion is to be monitored. The wearable device is equipped with an Inertial Motion Unit (IMU) with the purpose to detect the first phalanx orientation and a stretch sensor applied between the first and the second phalanx to recognize the flection angle. The configuration is completed with a microcontroller unit (ATmega328P) and a Bluetooth Low Power Module (RN4871) to ensure a reliable and easy to implement communication channel. We conduct two main set of tests to verify the global functionalities. In the first set the device is used to track the full flexion of a single finger while in the second we test the device capability to recognize different grabbed objects starting from the data retrieved from two fingers. The preliminary results open the possibility of a future development focused on a modular device composed by five elements, one for each hand finger and able to detect complex gesture like pinch, spread or tap.

Keywords: data glove, finger tracking, stretch sensor, inertial motion unit, human machine interface.

1 Introduction

In the last years, new devices and algorithms have been developed to implement innovative and accurate 3D body motion tracking systems [1]. These devices are widespread in fields such as medicine, automation, entertainment and are generically used to implement ergonomic human-machine interfaces. New methods allow capturing the movement of body parts such as hands, head or eyes, to issue commands to a computer, in order to achieve a more natural interaction [2]-[3]. Synergy between technology innovations and research activities led to several commercial devices with a great level of accuracy. Some optical tracking system reach a sub-millimeter accuracy grade thanks to the use of special markers, which makes them suitable for use in critical fields such as medicine as a support to surgery [4]. The development of new human hand tracking devices is one of the main lines of research. These devices can be categorized based on the motion capturing principle. The two main methods adopted are: optical-based and data-gloves. An optical-based system exploits image processing techniques to retrieve information about motion [5]. This approach leaves the hand free to move since there are not physical link to the measuring system, but the accuracy can be influenced by environmental factors such as illumination or extraneous objects in the camera line of sight. Furthermore, an accurate optical system generally requires expensive dedicate hardware with multiple cameras and illuminators. On the other hand, systems based on data gloves are slightly more invasive but generally produce more reliable data [6]. These devices are usually composed by a fabric glove in which bend or stretch sensors are integrated. The sensors are generally fixed between the interphalangeal joint and used to evaluate the angle formed between the phalanges. The purpose of this work is to develop a wireless wearable device able to track finger movements exploiting stretch sensors and inertial modules embedded in a highly integrated modular device that can be applied on each finger independently. In this way, according to the need, it is possible to reduce the inconvenience of wearing an entire glove when it is not required. For example, movement of a single finger can be used to control a computer cursor or to issue some commands through a simple gesture recognition. In other circumstances, when a virtual object must be manipulated, it can be necessary to track three or more fingers. Thanks to its modularity, the developed system can adapt to these different scenarios. The designed system can measure the flexion of the proximal phalanx analyzing data from an inertial module and exploits a stretch sensor to monitor the medial phalanx. A low power wireless communication method is used to transmit data to a specifically written computer program. The project therefore aims to develop an innovative device that can implement an accurate human-machine interface useful for biomedical, industrial or entertainment applications.

2 Description of the system

The overall system (Fig 1) is composed by two main parts. The first one is a physical measurement unit that can be applied directly on the finger (on the first and second phalanges) whereas the second one is an ad-hoc computer program written in LabVIEW (Virtual Instrument, VI). The measurement unit can recognize finger orientation in the space through an inertial motion unit rigidly coupled to the first phalanx. The angle formed between the first and the second phalanx is retrieved through a stretch sensor. Data are elaborated and prepared for the transmission by a microcontroller unit and then sent through a Bluetooth low power communication channel to the computer.

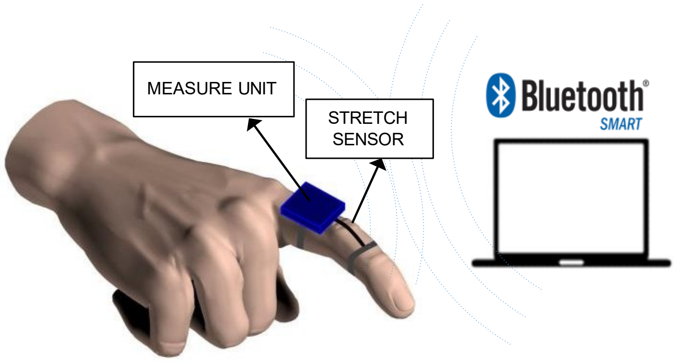
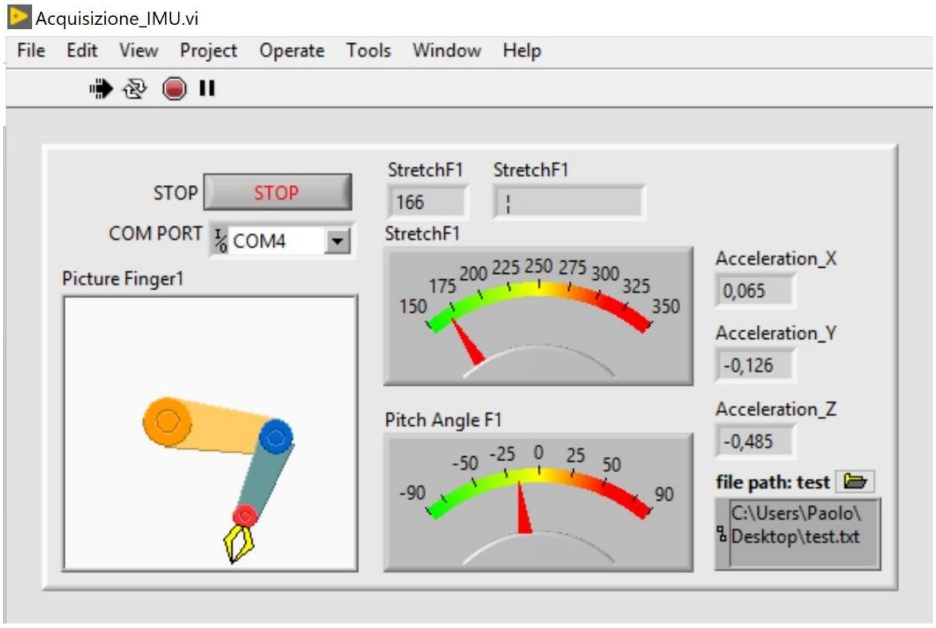


Fig. 1. General representation of the overall system.

The VI presents the data through graphical and numerical indicator. As it can be observed in Fig. 2 program user interface is divided in three main sections (vertically, from left to right). The first one is represented by a real time animation that shows the angles formed between the two proximal phalanges. The animation is driven by the pitch angle retrieved from the accelerometer section of the IMU (first phalanx) and by the resistance value of the stretch sensor. The second part includes two graphical indicators that display pitch angle and stretch sensor resistance respectively. The third part shows the raw acceleration along the three axes and the user selectable path where data file will be saved. The communication (computer side) is obtained through a USB-to-TTL-serial adapter (FTD232, from ftdi) connected to a Bluetooth Low Energy module (RN4020, Microchip). The VI receives raw data from the sensors without any kind of processing, in this way the computational load of the microcontroller on the wearable device is reduced and the elaboration is demanded to the computer. The data between the two Bluetooth modules are exchanged through the Microchip Low-energy Data Profile (MLDP), a proprietary BTLE service. Using this service, after the connection is established between the two modules, virtual UART channel is created and every byte asserted on a module is automatically transferred. The maximum throughput of the MLDP protocol is 50 kbps which is considered enough in this case and even permits to transfer data in ASCII format rather than binary. Therefore debug process is simplified thanks to the readability of the strings sent. In this preliminary phase of the project the ease of implementation is preferred to the energy saving. However, as the wearable device is powered by a small size battery (25 x 25 mm, 44 mAh) the battery life will be a primary aspect in the next prototype. To decrease the power consumption wireless connection speed will be reduced to the minimum that permits the proper system operation. In addition, the specific energy-saving features of the individual components will be enabled to achieve greater efficiency.



STOP: STOP

COM PORT: COM4

StretchF1: 166

StretchF1

Acceleration_X: 0,065

Acceleration_Y: -0,126

Acceleration_Z: -0,485

file path: test: C:\Users\Paolo\Desktop\test.txt

Fig. 2. User interface of the LabVIEW developed program.

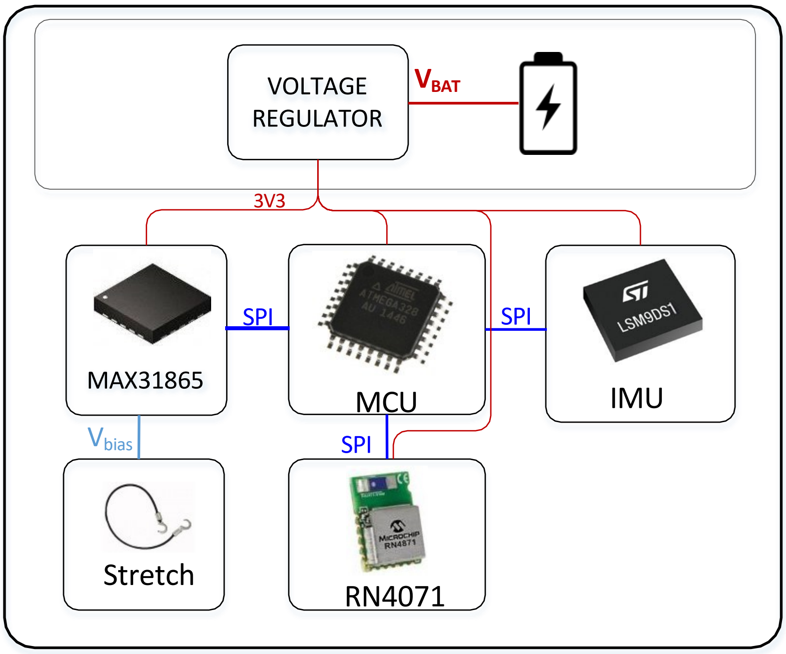


Fig. 3. Block diagram of the measuring unit.

The measurement unit (Fig. 3) is composed by several parts. A microcontroller unit, ATmega 328P, manages all the peripherals connected, reading the sensors and transmitting the data. To simplify the implementation the microprocessor firmware is written using the Arduino IDE to take advantages of the peripheral libraries. Finger 3-D orientation is captured by an Inertial Motion Unit (LSM9DS1 from STMicroelectronics). This device includes in a single chip an accelerometer, a gyroscope (the inertial section) and a magnetometer. It has dedicated power saving functions that permits to selectively reduce the performance (or turn off) of every section when not in use. The flexion of the proximal phalanx is detected through a stretch sensor (by Images Scientific Instruments Inc.), which is composed by a conductive rubber that increases its resistance when stretched. To adapt to the length of the different fingers every sensor is specifically assembled starting from a defined length of the rubber filament with a pair of crimped conductive clasps at its edge. The rubber filament, according to the datasheet, has a resistance of about 395 Ω/cm. The measurement of stretch sensor resistance is delegated to a specific integrated circuit (MAX31865, Maxim Integrated), a device specifically designed to facilitate the resistance measurement. It has the capability of performing accurate resistance evaluation exploiting 2, 3, or 4 wires measuring technique to compensate the connections resistance influence. In this case, a 2-wire configuration is chose because of the shortness of the links. To ensure a low-power wireless capability, the system is equipped with a Bluetooth Low Energy module (RN4871, Microchip Technology). A two-ring support was developed to firmly apply the stretch sensor between proximal and intermediate phalanges.

3 Experimental study

Two main tests were performed to examine the system whole functionalities. The first one had the aim to verify system capability to recognize a full flexion and extension movement. As reported in Fig. 4, the system can discriminate between extended and flexed position. The resistance sets associated with the two positions examined are never overlapped. Also considering the variability between successive measurements the sets are always disjointed. In the extended position, according to stretch sensor characteristics [7], resistance value decays slowly, so it is important to fix a threshold below which the finger is considered fully extended. The IMU is used to measure the pitch angle of the proximal phalanx with respect to the horizontal line. Starting from the gravity acceleration detected on the three axes, the angle value is obtained using (1).

$$\theta = \operatorname{atan}\left(\frac{G_y}{\sqrt{G_x^2+G_z^2}}\right) \tag{1}$$

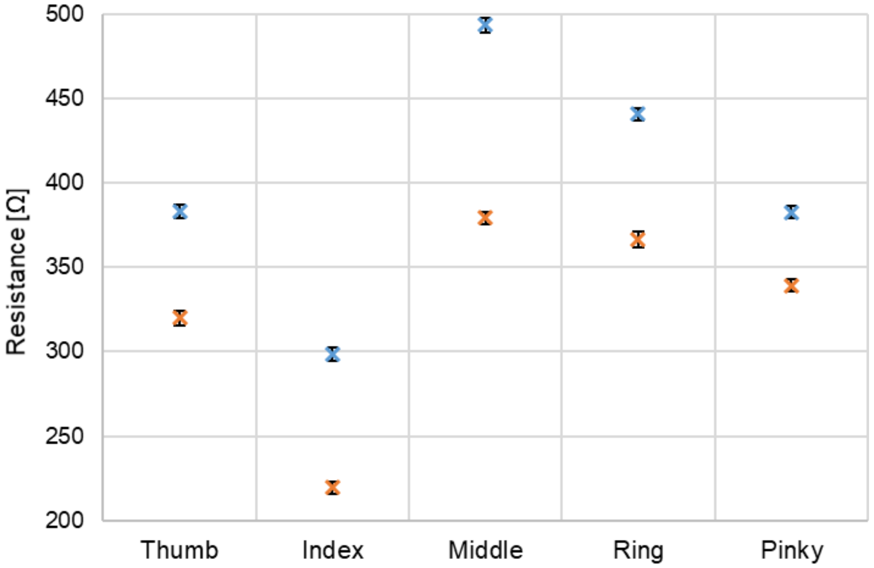


Fig. 4. Stretch sensor resistance for flexed (blue) and extended (orange) position.

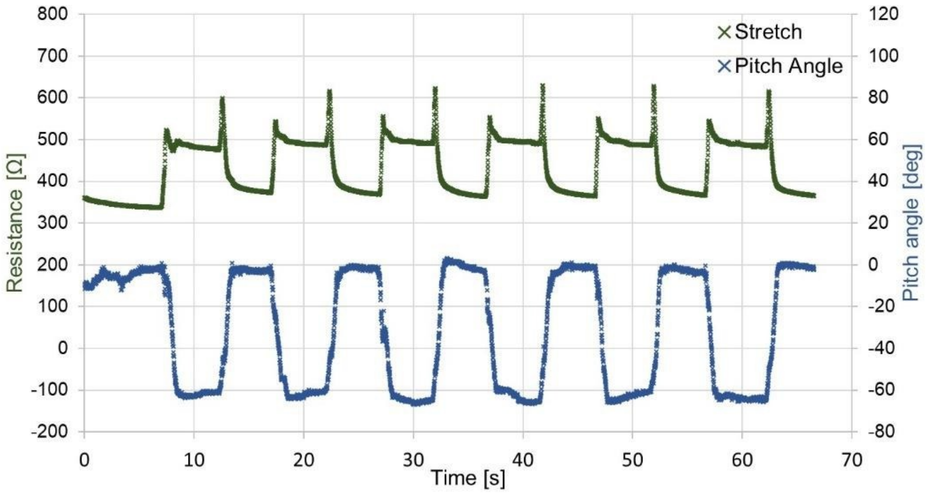


Fig. 5. Full finger extension, signals from IMU (blue) and stretch sensor (green).

In Fig. 5, the first test results are reported. In the first track (green) are visible the resistance values from the stretch sensor: lower values for extended position and higher for flexed position. In the second track are reported the pitch angle values of the first phalanx. Comparing this data, it is possible to observe that the system detects both positions correctly. Furthermore, a second set of tests was performed to establish if the system can discriminate between two different grabbed objects. Two stretch sensors were applied to index and middle fingers. The different diameter of each object leads to different flexion angles and then to a different stretch sensor resistance variation. After a first training phase in which the two objects are grabbed and released multiple times an average on the obtained data was performed. The results are arranged in Fig. 6. The left part of the figure shows the resistance value obtained for the index finger. The two sets of data are partially overlapped. On the other hand, the right part reports the resistance values for the middle finger. In this case, it is possible to observe that the overlapping is reduced to very few samples associated to the release position. As it can be observed by crossing the values from the two fingers, the system can detect which object was grabbed.

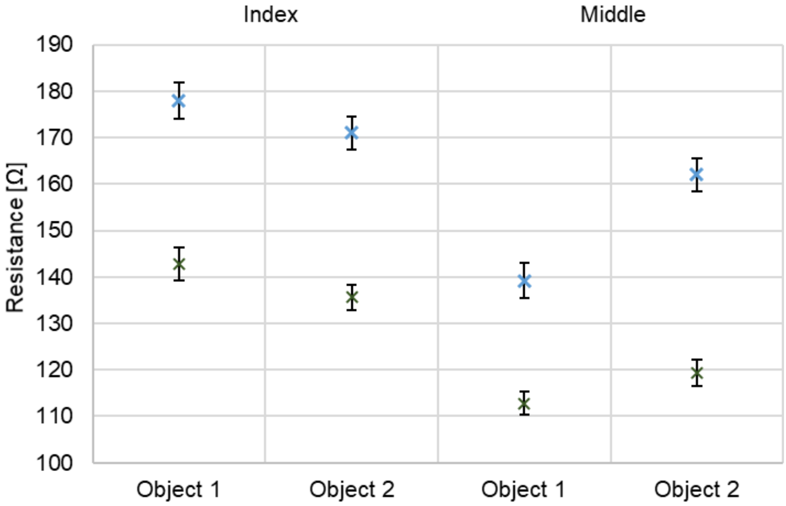


Fig. 6. Object grabbing recognition based on two stretch sensors, blue: object grabbed, green: object released.

4 Conclusions

In the presented work, a prototype version of a modular device able to track the movements of a single finger has been developed. The system is composed by a small-size wearable device and a computer program that acts as a readout unit. The communication between the two parts is implemented through a Bluetooth low power connection. The preliminary results show that the device can track simple movements such as full flexion and extension of the first and second phalanges in a normal context where the range movement last about 0.5 s. Further analysis will be conducted to understand the frequency limit of the used stretch sensor used. The inertial unit has a specified bandwidth of 408 Hz, since it is reported [8] that the fastest hand motions including handwriting can be tracked with a sample frequency of 10 Hz. For this reason, the IMU it is certainly suitable. In the second set of experiment, we tested if the system (applied to two fingers) can discriminate between two grabbed objects. Even if these tests were carried out using two objects of very different diameters the authors are confident that crossing the data retrieved from a full 5-fingers implementation can increase recognition accuracy after a proper training phase. The preliminary results open the possibility of a future development focused on a modular device composed by five elements, one for each hand finger and able to detect complex gesture such as pinch, spread or tap and to recognize different predefined object.

Acknowledgement

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