Dataglove for consumer applications

Low cost dataglove using optical fiber sensor

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Abstract— **Sensory gloves are promising technologies for human/machine interface and sign language translation. For theses applications, all degrees of freedom of the human hand have to be monitored with a good precision. For now, there is no sensory glove on the market meeting these requirements at low cost for widespread consumer applications. This paper describes a prototype of low cost sensory glove based on coupling loss fiber optics flexion sensors.**

Keywords-component; Dataglove, Flexsensor, sign langage, optical coupling loss

I. INTRODUCTION

With the increasing presence of electronic systems in our everyday life, there is a need for more polyvalent and intuitive ways to interact with electronic environments. With these tools, computing power can be used for novel applications. Exemples are Wiimote and Kinect in entertainement, touch screens and multipurpose remote controls for domestic applications. Translation of the human movements into useful informations is a challenge because of the multitude of degrees of freedom.

The part of our body which is most used to interact with our environment is our hand. But it is also the part that has the most degrees of freedom. Having a technology that could translate position and movement of the hand to computer opens the way to a more polyvalent and intuitive ways of interacting with virtual objects. Applications such as sign language translators [1], or dexterity training software could then be developed. With the introduction of sensory gloves by Sandin et al. [2], such systems are now possible. Since then, many types of sensory gloves have been put on the market. These technologies have made many novel applications possible. Precise and intuitive control of robotic arms for remote surgery is a good example [3]. But so far, sensory gloves do not offer the compromise between precision and price needed for widespread applications. Furthermore, many designs do not monitor enough degrees of freedom, which limits there applications [4, 5, 6, 7]. Research are on going to create less expensive gloves [8] sensing enough degrees of freedom to enable sign language translation [1]. Unfortunately, these gloves do not offer enough ergonomics to be used continuously.

Making use of the flexibility and low cost of fibre optics, a flexion sensor prototype suitable for widespread consumer applications has been developed. With further developpement, an angular precision of 1° can be achieved. A sensory glove system based on these sensors can be made for a cost 10 times inferior to those available on the market. This paper presents a sensory glove prototype using fiber optics sensors for shaping the hand and Micro-ElectroMechanical System (MEMS) gyroscopes for positionning the hand.

II. FLEXION SENSOR

Many types of fibre optic flexion sensors have been concieved. But for wide spread applications, these sensor have to be robust, low cost and offer a good precision and ergonomics. Two types of designs have been chosen to measure flexion and abduction of the fingers.

A. Coupling loss sensors

During flexion of the finger, the tension at the exterior of the phalanx can be used to stretch a surface. This is the operation principle Flexsensor [9]. In our sensor, the fibre is fixed with the detector at one end and the other end is incerted into a cylindrical guide. A light emitting diode (LED) inside the tube is used as a source and coupling loss are increased during the flexion of the finger. (See figure 1).

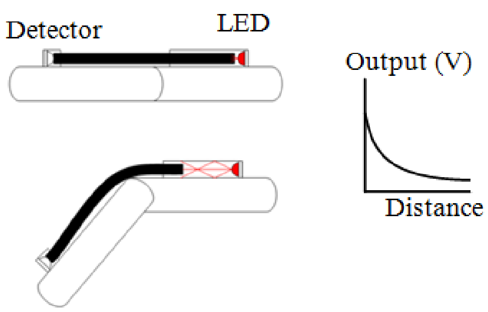

Figure 1. Type I optical flexsensor using fiber optics coupling loss.

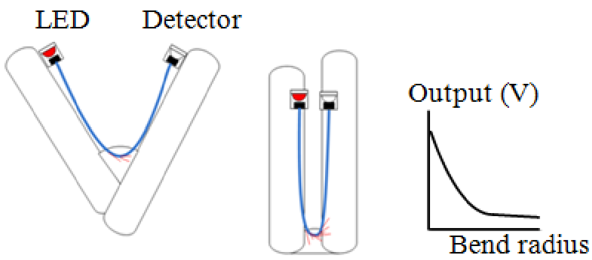

Figure 2. Type II optical flexsensor using fiber optics bending loss

B. *Bending loss sensor*

Abduction (splitting) of two fingers can be measured using a fibre optic attached to both fingers. During abduction, the radius of curvature of the fiber will increase. As a consequence, bending loss will decrease. Thus, the voltage at the detector will increase (see figure 2).

III. THE PROTOTYPES

Two sensory gloves prototypes were built. The first one was meant to the proof of concept of the flexion sensors. The second was designed has a sign language traduction interface. Development of the complete system requires installing the sensors on the glove, designing signal acquisition electronics, interfacing with a computer, signal processing and data display. These datas where then used for control of a humanoïde robotic hand and dynamic 3D reproduction of the hand.

A. *Summary of the system*

The systems measures the 4 adbuction mouvements of the hand, 2 flexion mouvements per fingers, except for the thumb where 3 flexion mouvements are measured. For the fingers, the flexion mouvement of the last phalanx is omitted because it is directly correlated with the mouvement of the midle phalanx. Horizontal and vertical flexion and abduction of the wrist is also measured. A total of 17 mouvements have to be monitored simultaniously by the system.

Reproducibility of the measurements is assured by fixing the detectors onto a rigid surface (See experimental part). Variation of the signal cause to elastic deformation of the glove is therefore reduced. Positioning of the components was optimised for comfort. Two MEMS gyroscope are used for

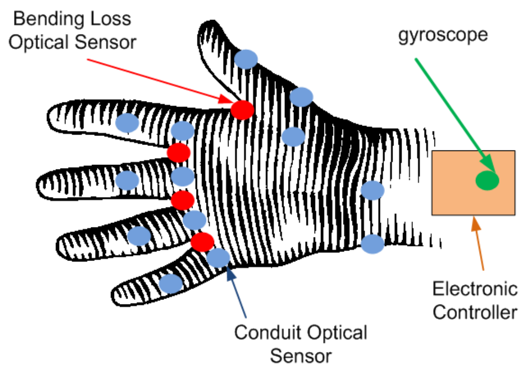

Figure 3. Sensors position on sensory glove

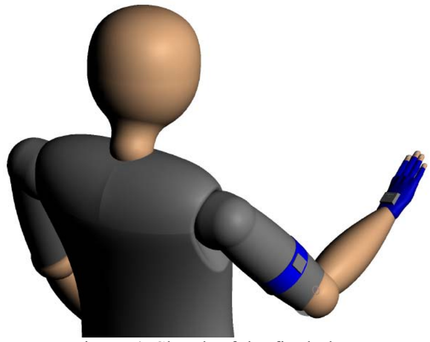

Figure 4. Sketch of the final glove

spatially positioning the hand. One is place on the fore arm and the other one on the arm. This is sufficient for sign language translation and virtual environment interaction. Figure 3 shows the position of the sensors. Figure 4 shows a sketch of the whole sensory glove.

IV. EXPERIEMENTAL RESULT

The following section presents the results of tests on the flexion sensors. The performance characteristics of the prototype are also given.

A. *Characterization of the coupling loss flexion sensor*

Flexion sensors are built using a LED with peak emission at 940nm (model LTE-4602), a compatible phototransistor (model LTR-4602) and a 1mm diameter polymeric (PMMA) optical fiber with a protective sheat. An electronic circuit amplifies the signal from the phototransistor and maintains stability of the LED emission intensity using a 3-terminal adjustable regulator (model LM317).

Figure 5 show the response of the flexion sensor for different values of the resistor in series with the photodetector. The distance was measured by a micropositioner. Based on theses results, a resistor of 680Ω was chosen. Figure 6 show the effect of the LED driving current on the response of the flexion sensor. The driving current is adjusted for each individual sensor because every phalanx does not have the same maximum amplitude. These adjustements are meant to optimize the dynamic range of the sensors for each phalanx. A 2-point calibration is used for the adjustements since the response of the sensors can be considered linear.

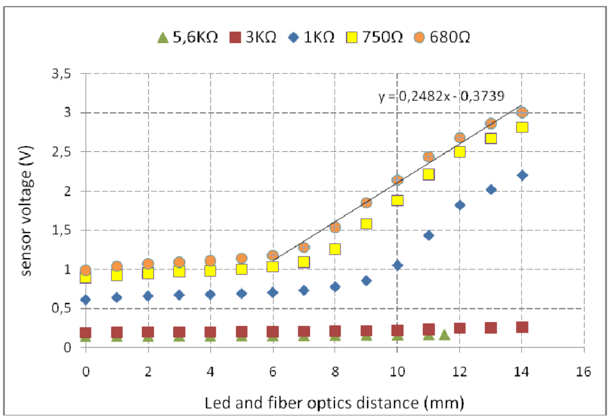

Figure 5. Resistance variation test with a source at 20mA.

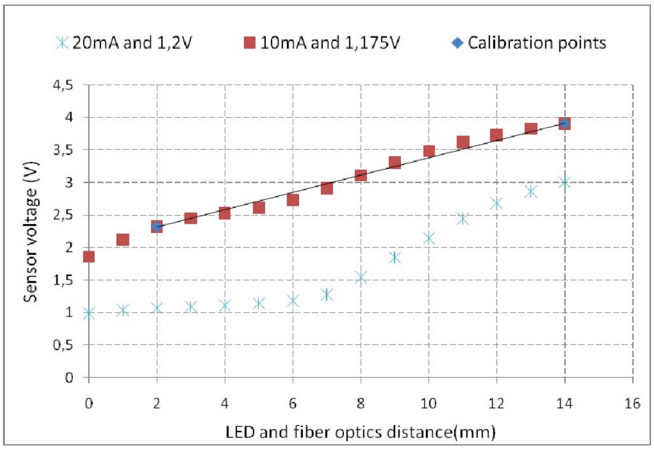

Figure 6. Source power variation test with a resistance of 680Ω

This 2-points calibration can be achieved by considering proportional the relationship between the angle of the joint θ and the distance between the fiber optics and the LED x. The joint may be considered like a circle of radius r connected to two phalanges (see Figure 7). Equation (1) gives the linear relationship of x versus θ. The radius r and the maximum angle θ thus determine the dynamic range of a joint. Because each has a different radius of curvature r and a maximum angle θ an average of these two values was made. This gave an average maximum deviation of 12mm and an average maximum angle of 100°. These values will be used to calculate the expected precision.

$$x\ [mm] = \frac{\theta\ [°]}{180°}\,\pi\, r[mm] \tag{1}$$

The 2-point calibration line is shown on figure 6. The maximum deviation is 0,58mm over the total average dynamic range. The average maximum uncertainty is 4.8% which corresponds to an angular precision of 4,8° using the average maximum degree.

This precission could be enhanced using a two stage calibration. A pre-calibration stage would be used to account for the sligth nonlinearity of the detector's response by spline.

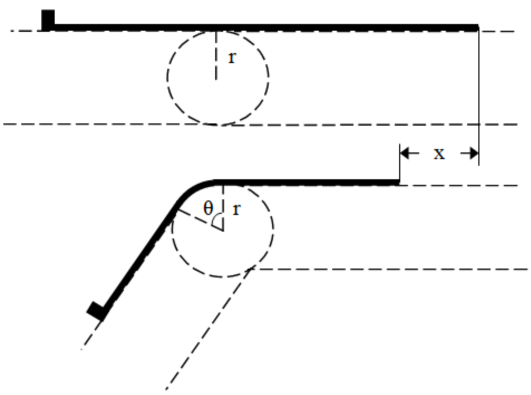

Figure 7. Linear deplacement of the fiber optics during the flexion

A 2-points calibration stage is still required to define the dynamic range of the sensors to the user's anatomy. Repeatability was tested by means of 3 tests of 50 repetitions each. Mesured values were within ±0,1mm which corresponds to an angular variation of ±0,85° using the average dynamique range. These tests show that reapeatabiliy of the measurements are good enough to reach an angular precision of 1° with a rigourous 2 stage calibration.

B. *Characterisation of the bend loss flexion sensor*

These sensors can measure abduction of two figers. They are made with the same materiel that the coupling loss sensors expect that the optical fibre is an unsheated PMMA fiber.

I was found that to obtain bend losses significant enough to enable angular precision of 1° degree, radius of curvature of less than 2mm has to be reached. With such high radius of curvature, plastic deformation occurs in the fiber which degrades the measurements in the long term. For this reason, this sensor had to be rejected and other protoypes are under test. Therefore, the sensory glove prototypes does not account for the abduction mouvement of the fingers.

C. *Characterization of the prototypes*

Precision of the sensory glove system was measured using dynamic 3D reconstruction (see figure 8). It was done by comparing the angle between the promixal and intermediate phalanx given by the 3D reproduction with the real value. The deviation of the 3D reconstruction to the real value was within 6°. This prototype garanties an angular precision of 6°. The accuracy obtained is lower than the expected accuracy. This reflects the fact that we have considered the joint as a simple circle.

The assembly was hand made without specialised equipement. It would be possible to reah a higher angular precision by refining the fabrication methods. For exemple, finer polishing of the fiber ends, improved coupling of the phototransistor and conception of a better cylindrical guide.

Table I shows the detail of the material cost from the production of one glove. Considering the ease of production of the prototype and its low material cost, we estimate a market price between 250 and 500$ CAN for a futur consumer product.

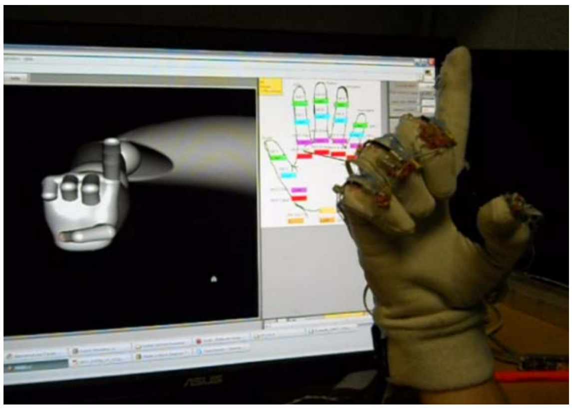

Figure 8. Dynamic 3D reproduction of the hand mouvements

TABLE I. Material cost for 1 glove of mass production

Part	Unit cost	Nb	Total cost
LED	15 ¢	17	2,55 $
Photodiode (détecteur)	15 ¢	17	2,55 $
Optical fibre	1 ¢ / 5cm	17	0,17 $
Mechanical parts	1 $	17	17,00 $
Glove	5 $	1	5,00 $
Gyroscope	8 $	2	16,00 $
Controller and PCB	30 $	1	30,00 $
Total cost:			**73,27 $**

A comparable product available on the market is the 5DT Glove 14 Ultra Right-handed marked around 5200$ CAN. This sensory glove uses 14 fiber optics flexion sensors with a precision of 1°. Unlike our prototype, this product does not include a positionning system and monitors less degrees of freedom.

V. CONCLUSION

Sensory glove for everyday use would be profitable for many people. Accessibility to precise and ergonomic sensory glove for consumer applications is now limited because of their high cost. A prototype based on fibre optic flexion sensor and MEMS gyroscope for spatial positioning has been developed. The prototype was proven precise, ergonomics and economic.

The flexion sensors we have developed are based on optical coupling loss and have an angular precision of 5°. Because of their low cost, ten times cheaper sensory gloves can be built with these sensors. Flexion sensors based on bend loss were not used because of plastic deformations that were degrading the sensor's performance. Flexion sensors capable of measuring the flexion of the finger are still under development.

Two prototypes of sensory gloves have been built, one as a proof the concept of the flexion sensors and one as an interface for sign language traduction. These prototypes have shown an angular precision of 6° using a single stage 2 point linear calibration. A two-stage calibration scheme could further improve the precision down to 1° concidering the fact that reapetability of the measurements are within ±0,85°

Sensory gloves compatible with consumer use would revolutionize in the way we interact with electronic systems. With the possibility of reproducing the movement of the hand enables the interaction with a 3D virtual world. The sensory gloves could be used for re-adaptation of injured patients or for dexterity training for surgeons.

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