ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2020.0323

DESIGN AND DEVELOPMENT OF AN IMITATION ASTUTENESS FOR SINGLE ARM AMPUTEE USING WIRELESS SENSOR NETWORK

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Abstract

In this paper, present a wearable detecting glove with inserted hetero-central element optic nerve sensors that identify finger flexion to realize unconstrained hand movement checking. The hetero-main element sensor is fit to the wearable detecting glove since it's fit for optical force based estimations with great security and repeatability utilizing single-mode transmission filaments and is unaffected by temperature variances. The hetero-center sensor components are situated on the back of the hand so as that they are not influenced by arbitrary wrinkles inside the glove at the joints. Subsequently, the hetero-center flexion sensor after adjustment is equipped for recognizing the joint edges of the fingers regardless of contrasts close by size, and in this way the hetero-center detecting strategy empowers the distinguishing glove to be worked with a base number of sensor centers. The optical loss performance of the hetero-core sensors reveals monotonic characteristics with regard to the flexion angle of joints. The optical loss is 1.35dB for a flexion angle of roughly 97.2° with accuracy of 0.89◦ within the detected flexion angle. Ongoing hand movement catch was exhibited by methods for the proposed detecting glove without limiting normal human conduct.

Keywords:

Hand Motion Monitoring, Hetero-Core Fiber, Glass Fiber Measurement Applications, Unconstrained and Wearable

1. INTRODUCTION

Wearable motion capture systems have extensively been developed and used in many fields such as virtual reality, sports biomechanics, and rehabilitation engineering. In particular, wearable sensing gloves for hand motion analysis have been used with immersive virtual reality applications and robotic teleportation [1]-[2]. A large number of sensors must be embedded in sensing gloves with some other input interfaces to detect the degrees of freedom (DOFs) in the fingers and to apply them to a variety of hand sizes. Wearable sensing glove technology has therefore aimed at reducing the number of sensors for low-cost and long-term monitoring without disturbing natural activity. Wearable sensing gloves have conventionally been developed using magnetic induction coils [3] and electro conductive fibers [4]-[6].

Magnetic induction technology has enabled the sensing glove to have half the number of sensors as the number of DOFs in the hands. However, the generator coils must adapt the time- division method used to scan the coils to compensate for magnetic interference. On the other hand, electro conductive fiber techniques can detect strain and displacement and can be integrated into a garment during the fabric manufacturing processes. However, in principle, electro conductive fibers have a nonlinear response and a long relaxation time for a steady state. Optical fiber sensors have many well-known advantages, such as being lightweight, flexible, and immune to electromagnetic interference.

Some fiber-optic sensing schemes have been reported for bending and strain measurement using Fiber Bragg Gratings (FBGs) [7], long-period fiber gratings [8], and cut-in Plastic Optical Fiber (POF) sensors for Shape Tape [9]. POF sensors have also been utilized to detect the flexion angles of finger joints [2] for commercial sensing gloves. However, FBG sensors are temperature dependent [10]-[11] and have some problems with cost efficiency, and POF sensors have limited stability using multimode fibers. Conventional fiber sensor techniques are therefore restricted with regard to wearable sensing of natural human motion during daily activities. In contrast to these conventional fiber-optic sensors, heretofore fiber-optic nerve sensors [12]-[16] may be considered applicable for sensing gloves because they are both wearable and capable of unconstrained motion monitoring. This is because the hetero-core sensor has been found to have highly sensitive and reproducible performance in response to macro bending based on optical intensity variations and is unaffected by temperature fluctuations.

Additionally, the hetero-core fiber sensor can offer the excellent stability advantages of single-mode transmission fibers. The performance Characteristics of a wearable motion analysis system [15] were reported, in which the entire body posture and motion can be monitored using hetero-core optic fiber sensors with their significant performances in terms of sensitivity, stability, and reproducibility due to the use of a single-mode propagation scheme. The unique characteristics of the wearable system for the entire body posture [15], the hetero-core fiber sensors need to be embedded in the small and specific area of the glove garment and be suited for various hand sizes.

Additionally, the embedding hetero-core sensor in our previous works was affected by random wrinkling of clothes. In this paper, we describe a wearable sensing glove equipped with hetero-core fiber-optic nerves that can detect the angles of finger joints, be adapted to various sizes of hand, and realize unconstrained hand motion analysis. The hetero-core optic nerve elements were embedded in the glove on the back of the hand. As a result, the hetero-core sensors are unaffected by random wrinkling at the joints in the glove and can detect the joint angles of fingers regardless of differences in inter phalangeal length. The hetero-core sensing technique thus enables the sensing glove to be equipped with a minimum number of sensors. The optical loss performance of hetero-core sensors has indicated monotonic characteristics with respect to the flexion angles of joints. Real-time hand motion capture was demonstrated using the sensing glove without restricting natural Sensing glove is presented for the analysis of hand motion.

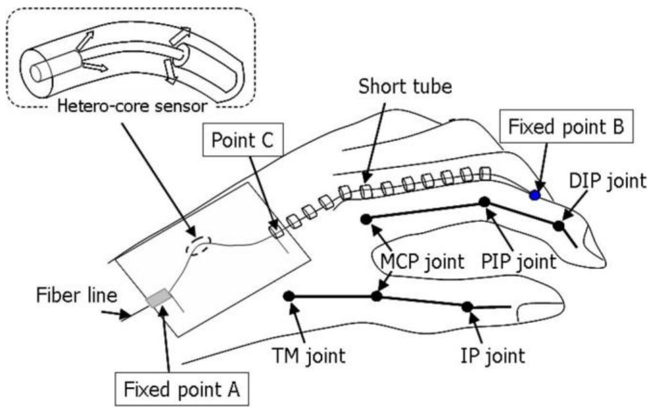


Fig.1. Configuration of the wearable sensing glove with embedded hetero-core fiber-optic nerves for monitoring hand motions and finger joints

2. PROBLEM STATEMENT

The proposed model of prosthesis hand replicates the real functional hand of the Amputee does. It will be helpful for amputees for doing simple jobs like lifting any objects with both hand and gripping any objects. It can also make them to read newspaper. It also helps to drive a gearless scooter. These applications may be viewed very simple to normal Human beings, but for the handicapped or amputees this applications are much useful Functional daily activities for them. The proposed system of our prosthesis hand has two units.

1. Smart Sensing Glove
2. Actuator unit

2.1 SMART SENSING GLOVE

The smart sensing glove is worn by the amputee of the normal hand. It contains the flex sensors to measure the amount of bending of the fingers. The flex sensor is connected to the voltage divider circuit. The reference voltage is given for the flex sensor and the voltage divider has a fixed resistor and a variable resistor. Our fixed resistor can be either 25kΩ or 10kΩ according to variations needed. Then the variable resistor is our flex sensors. This system is fixed in a glove and the amputee will wear this in the normal hand. The bending variations of the flex sensors in fingers are converted to varying voltage by the function of voltage divider. The analog value is converted to digital values by the ADC which is inbuilt in chosen PIC micro-controller. The values are sent to the actuator unit by the RF Transceiver.

2.2 ACTUATOR UNIT

The Actuator unit consists of PIC microcontroller, RF transceiver, Motor driver and the Motors. The Sensed data from the sensing glove will be received by RF transceiver and the motor driver drives the motor according to the sensed values. Microcontroller takes the decision here according to the sensed value and drives motor for the finger movement. The Actuator unit will be fixed for the prosthesis hand for the amputees. If the Amputee lost his left hand, he will be wearing the sensing glove in the right hand and the left hand will be the prosthesis hand driven by right hand motions

2.3 WEARABLE SENSING GLOVE WITH HETERO-CORE OPTIC FIBER SENSORS

The configuration of the wearable sensing glove with hetero core fiber-optic nerves to detect the flexion angles of finger joints without disturbance from random wrinkles is shown in Fig.1. As is indicated in Fig.1, each hetero-core fiber-optic nerve sensor consists of a transmission fiber line whose core diameter is 9μm and an inserted fiber segment whose core diameter is 5μm with a length as short as a few millimeters of fusion splicing. In our previous work, it was revealed that the optical loss of the hetero-core sensor linearly increases with the bending action of the hetero-core portion [14], [15]. The hetero-core optical fiber sensor has previously been investigated and developed for detecting the macro bending and deformation of smart materials [14], [15]. The hetero-core fiber sensor can therefore be used for hand motion analysis by arranging sensor units so that flexion of a finger joint effects corresponding bending in the hetero-core portion of a sensor.

As shown in Fig.1, the hetero-core sensors were arranged on the back of the hand in the glove, with two points of a fiber line directly fixed by means of adhesive (fixed point A) and the line placed through a short tube (point C). When a finger is stretched out, the flexion angle of the joint is defined to be 0◦. The fiber transmission lines were fed through short tubes adhered to the glove so that they could easily move. A fiber line was directly fixed at fixed point B on the segment of the finger between the Distal Inter Phalangeal (DIP) and Proximal Inter Phalangeal (PIP) joints of the index and ring fingers, or at the thumb tip and Inter Phalangeal (IP) joint, to yield an appropriate bending curvature in the hetero-core portion.

At fixed point B shown in Fig.1, the hetero-core sensors can detect the flexion angles of the Metatarsophalangeal (MCP) and thumb Trapezio-Metacarpal (TM) joints. When the joint of a finger is flexed, the optical loss of the hetero-core sensor changes due to the variation in the radius of curvature in the hetero-core portion, because the transmission line is pulled in the direction of fixed point B through the short tubes at the point C. To operate without influence from random wrinkles in the glove, the sensor portions themselves were placed away from the finger joints.

2.4 HETERO-CORE OPTICAL FIBER SENSORS AND THEIR SENSITIVITY

The Fig.2 shows an experimental setup for estimating the characteristics of the hetero-core fiber sensors used to detect the joint angles of the fingers. The flexion angle of the PIP joint (θ, in degrees), as shown in Fig.2, is given by θ = 2 arcsine $(d/2h)\bullet180/\pi$ where h and d are the thickness of the finger and the displacement of fixed point B, respectively.

The Fig.2 shows the experimental apparatus to induce the bending action of the hetero- core portion by changing the displacement of fixed point B using one controllable and two fixed stages. A laser diode with a wavelength of 1.31μm and an optical power meter were used to measure the transmission loss in response to the bending action of a hetero-core fiber-optic nerve sensor, which is the same as in our previous works. The hetero-core fiber sensor was set at the fixed and controllable stage at the two fixed points of the fiber by means of a fiber clamper (fixed point A) and direct adhesive (fixed point B). The fiber was placed through a short tube (point C) located at the other fixed stage.

The controllable stage regulates the distance of the displacement of fixed point B, i.e., *d*, to induce bending in the hetero-core portion. The hetero- core portion was placed between fixed point A and point C. The length of the clamped hetero-core fiber is 40 mm, between fixed point A and point C. The maximum displacement d_{max} = 15 mm corresponds to a flexion angle of approximately 97.2° with a finger thickness of 10 mm. The position of the hetero-core portion of the sensor unit was assumed to shift in the direction of fixed point A between fixed point A and point C, due to the displacement in the fiber line. The sensitivity could therefore be increased with the displacement in such a way that the position of the hetero-core portion was initially slightly closer to point C.

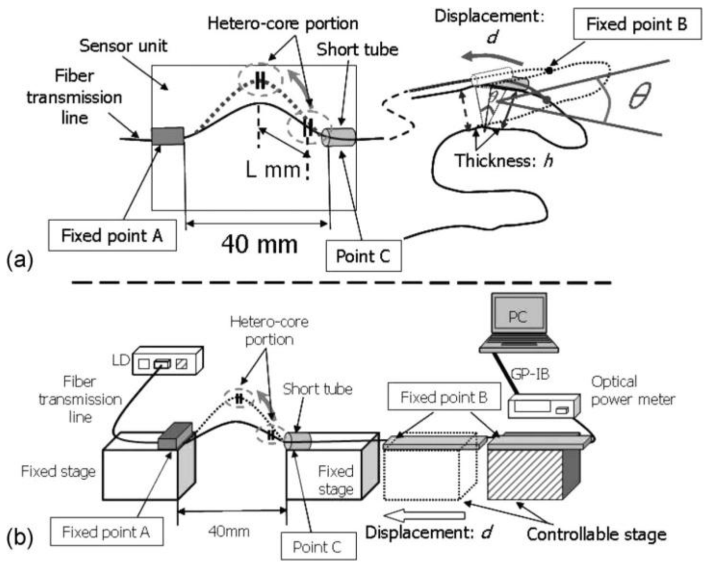


Fig.2. Experimental setup for estimating the characteristics of hetero-core fiber nerve sensors with respect to finger joint angles. (a) Conversion of the displacement d (in millimeters) of fixed point B to flexion angle θ (in degrees) with an initial shift of the hetero-core portion by *L* (in millimeters). (b) Experimental apparatus of fixed and controlled stages

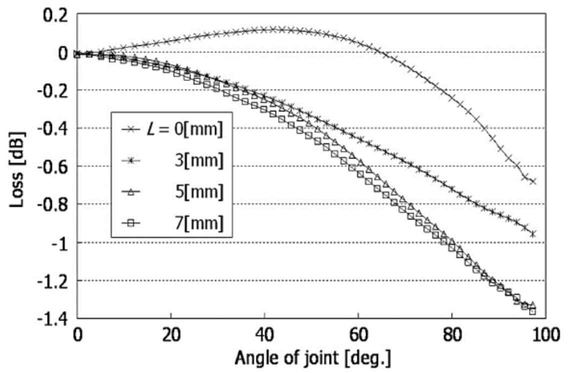


Fig.3. Optical loss responses of hetero-core fiber sensors according to finger joint angles for different initial positions of the hetero-core portion with *L* set to 0mm, 3mm, 5mm, and 7mm

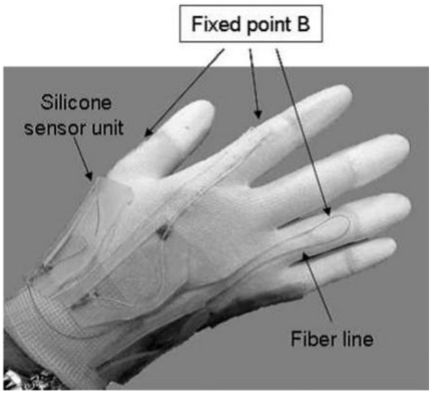
The initial shifted position of the hetero-core portion is indicated as L along the fiber line from the center of the two points A and C, toward point C. The Fig.3 shows the optical loss of the hetero-core fiber- optic sensor according to the joint angle of the finger for different initial shift distances of the hetero-core portion *L* of 0mm, 3mm, 5mm, and 7mm. In the case that *L* is more than 7.5 mm, the hetero core sensor is considered to be less sensitive to the flexion angle because the position of the hetero-core portion is shifted near fixed point A from the center of the two points A and C at the maximum displacement of 15 mm. Therefore, the hetero-core position *L* was employed to be less than 7.5 mm. In the case of the initial shift distance 0 mm, the optical loss of the hetero core sensor was not monotonic with respect to the flexion angle, as shown in Fig.3.

On the other hand, shifting the position of the hetero-core portion to 3mm, 5mm, or 7 mm caused the optical loss of the hetero-core sensor to be monotonic and quite linear with respect to the angle of the joint. Additionally, the sensitivity increased as the position of the hetero-core portion shifted. This is because the initial distance *L* shifted the position of the hetero-core portion by the distance set by the midpoint between fixed point A and point C, according to the displacement of fixed point B. Therefore, the radius of curvature in the hetero core portion is relatively small to induce high sensitivity in the hetero-core sensor because the initial position of the hetero-core portion is shifted toward point C. The sensitivity values for a flexion angle of approximately 97.2°, the standard deviations, and the accuracy values in detected flexion angle.

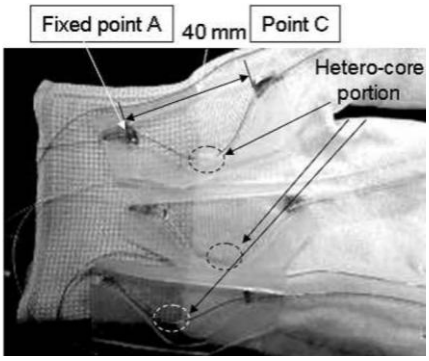
This experimental result revealed that the sensitivity with respect to the flexion angle of the finger was greatest at the initial shift distance of 7 mm. The optical loss was 1.35dB for a flexion angle of approximately 97.2° with standard deviation 0.91%, and the accuracy in the detected flexion angle was 0.89° with 20 trials. The deviation of the flexion angle measurement seems to be caused by the movement of the sensor portion, which is located in the fiber line. This is due to the fiber line passing through the short tubes. As the flexion angle of the hetero-core sensor response is measured, it could be detected by the optical loss of the hetero-core fiber-optic nerve sensor in real-time hand motion analysis.

3. REAL TIME HAND MOTION MOITORING

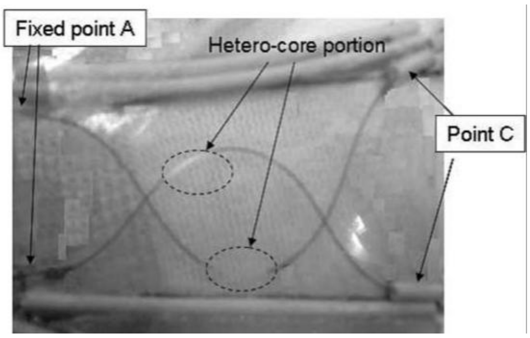
We fabricated two different versions of the wearable sensing glove equipped with hetero-core optic nerve sensors. In the first version, i.e., Type-I, the hetero-core fiber sensors were arranged in parallel, as shown in Fig.4(a) and Fig.4(b). The second version, i.e., Type-II, is equipped with paired hetero-core sensors piled as a single unit so that multiple sensors can be arranged, as shown in Fig.4(c). To detect the high number of DOFs in human hands and discriminate the movement of fingers and hand, multiple sensor elements must be located in a dedicated area of the glove. For the arrangement with the sensors piled into a single unit, it is possible that the compounded sensors could affect each other at the contact. The disturbance between two fiber lines due to contact interference can be eliminated by adhering the fiber lines at fixed point A. The glove garment is made from stretchable breathable nylon, which provides comfort for daily use and can repeatedly be used because the glove is a washable garment.



(a)



(b)



(c)

Fig.4. Image of the wearable sensing gloves (a) Wom by a subject (b) Type-I glove with three hetero-core sensors allocated in parallel on the back of the hand. (c) Type-II glove with two hetero-core sensors piled on a sensor unit

3.1 FLEXION CHARACTERISTICS OF THREE FINGERS IN PARALLEL

The Fig.4 shows the real-time response of wearable hetero-core fiber nerves in terms of the optical loss under the parallel Type-I arrangement, for periodic flexion of the thumb (Fig.4(a)), the index finger (Fig.4(b)), and the ring finger (Fig.4(c)). During the calibration process, the subject grasped their hand, and this posture was defined to correspond to 0dB. The simple calibration process could be implemented during motion analysis. As indicated in Fig.4, the wearable sensing glove could clearly detect real-time hand motion for each flexing finger. Focusing on the response to thumb motion, the optical loss at full flexion of the joint was less than 0dB because the full-flexion angle of the thumb IP joint is larger than when grasping with the hand. On the other hand, the optical loss at full flexion of the joints in the index and ring fingers is appropriately 0 dB, indicating that the calibration process was correctly achieved for repeated flexion motions with the fingers.

The sensitivity values at full flexion were approximately 1.0, 0.6, and 0.6dB for the thumb, index, and ring fingers, respectively, as shown in Fig.4. The wearable hetero-core sensors had lower sensitivity values than in the control experiment shown in Fig.4, due to the fact that the glove consisted of rubbery materials and the hands of subjects had various sizes and finger thicknesses. However, the simple calibration process could modulate the sensitivity to accommodate various sizes of hand, as described earlier in this paper. The change in the optical loss is larger for the thumb than for the fingers because the motion of the thumb was detected at the MCP and TM joints. The change in the optical loss was stable when the finger was straightened irrespective of wrinkles in the glove. The positioning of the hetero-core portion away from the joint thus enabled the sensing glove to be unaffected by random wrinkles, facilitating unconstrained hand motion analysis during natural activity.

The Fig.4 shows the optical loss of the hetero-core sensors embedded in the Type-I wearable sensing glove for flexion of the finger joints over ten trials. In the calibration step of this experiment, the optical loss of the hetero-core sensor was set at 0dB when each joint was flexed by bending all the joints of each finger. The optical loss values when the fingers were straightened were 1.04, 0.56, and 0.57dB with small standard deviations of 0.01dB for the thumb, index, and ring fingers, respectively, under a sufficiently high number of repeated measurements over ten trials. In the case that the IP of the thumb and the MCP of the ring finger were flexed, the hetero-core sensors induced relatively large deviations because the thumb IP and MCP joints are difficult to independently flex. When all fingers were stretched out, the hetero- core sensor had no deviations. Therefore, the difference of the flexion angle in several trials seemed to induce the deviation of the hetero-core sensor in the optical loss. With regard to the profile of the index finger, the optical loss when flexing the PIP joint at the same time as the MCP joint was sufficiently close to the sum of the optical losses due to flexion of the PIP and MCP joints independently.

3.2 MULTIPLE HETERO-CORE FLEXION SENSORS LOCATED IN PILES

The Fig.4 shows the real-time response of two hetero-core sensors embedded in the Type-II wearable sensing glove in terms of the optical loss. The hetero-core sensors were arranged in piles, and periodic flexion motions were performed with the ring finger (Fig.4(a)) and the little finger (Fig.4(b)), in turn. To eliminate the arrangement of multiple hetero-core sensors in the area of the glove dedicated to sensing units, the two hetero- cores optic nerve sensors for the ring and little fingers were allocated to a single sensor unit. As in the case described in Section 4(a), 0dB was defined to correspond to the grasped hand. As indicated in Fig.4, the wearable sensing glove also detects repeated flexion of the fingers in real time with two hetero-core sensors placed in piles at a single unit. Additionally, the signal from the side of the little finger (see Fig.4(b)) detects subtle motion of the little finger, which occurs in conjunction with the other finger motions. The ring finger profile in Fig.4(a) shows that the optical loss variation has high sensitivity for flexion motion because the ring finger is influenced by the motion of the other fingers. These results indicate that the wearable sensing glove is sensitive to subtle motions because the hetero-core sensor shows high sensitivity to subtle changes of curvature and has a low noise signal due to a stable SM transmission line and is effective given the displacement of fixed point B induced by flexion of the fingers. The multiple sensor arrangement of the Type-II glove was therefore shown to yield the high DOFs of the hand and detect subtle hand motions.

3.3 HAND MOTION CAPTURE IN 3-D VIRTUAL REALITY

A hand motion capture system was implemented in 3-D virtual reality software by converting the optical loss of the hetero-core sensors into the flexion angles of the fingers and presenting the hand posture, as shown in Fig.5. The real time motion capture system was efficiently demonstrated using the wearable sensing glove. Although the subject removed the glove between trials and replaced it, the hand motion was monitored in the same way as in the first trial. This is due to the arrangement of sensors on the back of the hand, away from the joints of the fingers; thus, the wrinkles of the glove do not change the hetero-core sensing properties related to the motion of the hand, such as flexing of fingers and removing or replacing the sensing glove. As a result, the wearable sensing glove is well suited to practical use.

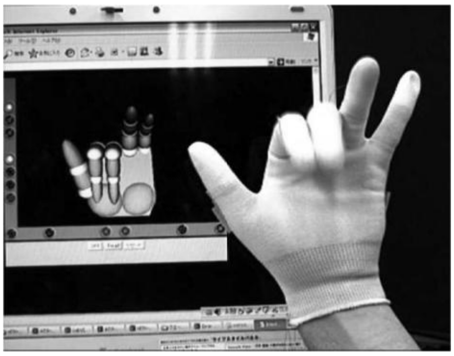


Fig.5. Hand posture monitoring system in virtual reality using the wearable sensing glove with embedded hetero-core sensors

4. CONCLUSION

In this paper, we have described the performance characteristics of embedded hetero-core optic fiber nerve sensors, which were used to develop a wearable sensing glove form monitoring finger flexion. The hetero- core sensor elements were embedded in the back of the glove, and as a result, the hetero-core sensors were unaffected by random wrinkles at the joints, and the glove was able to detect the angles of the joints regardless of differences in inter-phalangeal length. The optical loss performance of the hetero-core fiber nerve sensors revealed monotonic characteristics with respect to joint flexion angles in the controlled experiments. The changes in the optical loss of the wearable hetero-core nerve sensors at full flexion of the finger joints were 1.04, 0.56, and 0.57dB with 0.01dB standard deviations for the thumb, index, and ring fingers, respectively. As a result, the hetero-core sensor had sufficiently high sensitivity and accuracy that it could be used to monitor hand postures and motions. Real- time hand motion capture in 3-D virtual reality was demonstrated with a subject who put on the wearable sensing glove and repeatedly stretched and bent the finger joints. In conclusion, the wearable sensing glove with hetero-core fiber nerves is useful for monitoring unconstrained hand motions in various applications such as virtual reality and robotic teleportation

REFERENCES

[1] D.J. Sturman and D. Zeltzer, "A Survey of Glove-Based Input", *IEEE Computer Graphics and Applications*, Vol. 14, No. 1, pp. 30-39, 1994.

[2] T. G. Zimmerman and J. Lanier, "A Hand Gesture Interface Device", *Proceedings of International Conference on Human Factors and Computer Systems Graphics Interface*, pp. 189-192, 1987.

[3] C.S. Fahn and H. Sun, "Development of a Data Glove with Reducing Sensors based on Magnetic", *IEEE Transactions on Industrial Electronics*, Vol. 52, No. 2, pp. 585-594, 2005.

[4] E.P. Scilingo, F. Lorussi, A. Mazzoldi and D. De Rossi, "Strain-Sensing Fabrics for Wearable Kinaesthetic-Like Systems", *IEEE Sensors*, Vol. 3, No. 4, pp. 460-467, 2003.

[5] F. Lorussi, E.P. Scilingo, M. Tesconi, A. Tognetti and D.D. Rossi, "Strain Sensing Fabric for Hand Posture and Gesture Monitoring", *IEEE Transactions on Information Technology in Biomedicine*, Vol. 9, No. 3, pp. 372-381, 2005.

[6] R. Wijesiriwardana, "Inductive Fiber-Meshed Strain and Displacement Transducers for Respiratory Measuring Systems and Motion Capturing Systems", *IEEE Sensors*, Vol. 6, No. 3, pp. 571-579, 2006.

[7] A.D. Kersey, M.A. Davis, H.J. Patrick, M. LeBlanc, K.P. Koo, C.G. Askins, M.A. Putnam and E.J. Friebele, "Fiber Grating Sensor", *Journal of Lightwave Technology*, Vol. 15, No. 8, pp. 1442-1463, 1997.

[8] V. Bhatia, "Optical Fiber Long-Period Grating Sensors", *Optics Letters*, Vol. 21, No. 9, pp. 692-694, 1996.

[9] L. Danisch, K. Englehart and A. Trivett, "Spatially Continuous Six Degree of Freedom Position and Orientation Sensor", *Sensor Review*, Vol. 19, No. 2, pp. 106-112, 1999.

[10] H.J. Patrick, G.M. Williams, A.D. Kersey, J.R. Pedrazzani and A.M. Vengsarkar, "Hybrid Fiber Bragg Grating/Long Period Fiber Grating Sensor for Strain/Temperature Discrimination", *IEEE Photonics Technology Letters*, Vol. 8, No. 9, pp. 1223-1225, 1996.

[11] B. Guan, H. Tam, X. Tao and X. Dong, "Simultaneous Strain and Temperature Measurement using a Superstructure Fiber Bragg Grating", *IEEE Photonics Technology Letters*, Vol. 12, No. 6, pp. 675-677, 2000.

[12] K. Watanabe, K. Tajima and Y. Kubota, "Macrobending Characteristics of a Hetero-Core Splice Fiber Optic Sensor for Displacement and Liquid Detection", *IEICE Transactions on Electronics*, Vol. 83, No. 3, pp. 309-314, 2000.

[13] M. Nishiyama, H. Sasaki and K. Watanabe, "Restraint-Free Wearable Sensing Clothes using A Hetero-Core Optic

fiber for Measurements of Arm Motion and Walking Action", *Proceedings of Society of Photo-Optical Instrumentation Engineers*, Vol. 6529, pp. 652-652, 2017.

[14] M. Nishiyama, H. Sasaki and K. Watanabe, "A Deformation Sensitive Pad Structure Embedded with Hetero-Core Optic Fiber Sensors", *Sensors and Actuators A: Physical*, Vol. 136, No. 1, pp. 205-211, 2007.

[15] M. Nishiyama, H. Sasaki and K. Watanabe, "Performance Characteristics of Wearable Embedded Hetero-Core Fiber Sensors for Unconstrained Motion Analyses", *Transactions of the Society of Instrument and Control Engineers*, Vol. 43, No. 12, pp. 1075-1081, 2007.

[16] M. Nishiyama, H. Sasaki and K. Watanabe, "Optical Intensity-Based Measurement of Multipoint Hetero-Core Fiber Sensors by the Method of Time-Differentiation in Optical Loss", *IEEE Sensors*, Vol. 8, No. 7, pp. 1055-1060, 2008.