Characterization of Hand Movements using a Sensing Glove in Hand Assisted Laparoscopic Surgery

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ABSTRACT

The past thirty years have seen increasingly rapid advances in the field of laparoscopic surgery, in part because of the use of robots. A well-known example is the da Vinci surgical system. However, far too little attention has been paid to Hand Assisted Laparoscopic Surgery (HALS), a surgery in which the surgeon introduces the non-dominant hand into the abdomen of the patient. The risk of collision between the hand of the surgeon and the tool moved by the robot is the reason why these robots for laparoscopic surgery are not appropriate for HALS. On the other hand, in recent years, there has been an increasing interest in wearables, which have been introduced in our daily life. This interest and the lack of surgery robots for HALS are the reasons to develop a sensing glove which co-works with a collaborative robot in this kind of surgery. The aim of this paper is to study the use of a sensing glove which will provide information of the movements of the surgeon's hand to the collaborative robot. This information determinates the actions that the robot will carry on. The first step was to define different movements of the hand which could be identified. An algorithm identifies these movements using the data given by the sensing glove. For the purpose of algorithm accuracy measurement, 4 persons wearing the sensing glove made a sequence with different movements. The evidence from this study suggests that a sensing glove can be used to send information of the movements of the surgeon's hand to a collaborative robot during a HALS.

CCS Concepts

• **Mathematics of computing** → **Probability and statistics** • **Hardware** → **Communication hardware, interfaces and storage** → **Sensors and actuators. statistics** • **Hardware** → **Communication hardware, interfaces and storage** → **Sensor devices and platforms.**

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ICBBE 2017, November 12–14, 2017, Seoul, Republic of Korea

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ACM ISBN 978-1-4503-5484-4/17/11...\$15.00

DOI: <https://doi.org/10.1145/3168776.3168793>

Keywords

Hand Assisted Laparoscopic Surgery (HALS); Sensing Glove; Wearable; Collaborative Surgical Robot.

1. INTRODUCTION

Hand assisted laparoscopic Surgery (HALS) is defined as a laparoscopic surgery in which the surgeon introduces the hand into the patient's abdomen. Compared with the standard laparoscopic surgery, this technique provides the surgeon the sense of the touch and the skills to suture and dissect with the hand [10], [14]. The mentioned surgery also offers advantages opposite to the laparotomy as shorter hospitalizations, fewer incisions or less bleeding [8], [11].

Standard laparoscopic surgery has been advancing with the development of surgical Robots like BROCA [18] or da Vinci [19]. The mentioned robots, due to its nature, cannot be used in HALS because they are not able to infer when the surgeon needs some kind of help. In this sense, we propose the use of a collaborative robot guided by an algorithm that continuously recognizes the movements accomplished by the non-dominant hand of the surgeon. When a gesture is recognized, then it is planned in advance the robot movement needed to assist the surgeon immediately. The dynamic gestures can be collected by a sensing glove, which have undergone in the last years an increasing development that has promoted its use in different fields from the rehabilitation to the interpretation of the sign language [19].

The sensing glove was conceived as an ideal instrument for measuring hand kinematics during daily life situation for application in rehabilitation, virtual reality, musical performance, video games, teleoperation and robotics [12][6][13][3]

The sensing glove used in this study was developed previously for a specific project in which the objective was to evaluate the residual hand function of post-stroke patient and its recovery [15]. In particular, the sensing system was designed to assess user grasping activity through an unobtrusive and wearable interface based on textile goniometers placed in correspondence of principal hand joints.

Using this above-mentioned glove, several movements of the hand have been studied and an algorithm has been developed for the detection of some specific gestures. Different movements have been defined considering the movements that the surgeon realizes during a HALS [1]. The above-mentioned defined movements cannot be identified as the movements realized commonly during the operation. They will be sent to a recognition system and global

management to generate the pertinent commands that will be sent to the collaborative robot for its execution along the surgery.

2. METHODS AND MATERIALS

2.1 KPF Goniometers

Textile-based sensors were realized using knitted piezoresistive fabrics (KPF) structured with 75% electro-conductive yarn (Belltron, produced by Kanebo Ltd) and 25% Lycra, manufactured as single jersey in a circular knitting machine as described in previous works [16],[17],[5].

KPF goniometers consist of two identical piezoresistive layers connected through an electrically-insulating layer (Figure 1-a). As reported in [17] the sensor output, the electrical resistance difference (ΔR) calculated from the two sensitive layers, is proportional to the flexion angle (θ), represented as the angle delimited by the tangent planes to the sensor extremities (Figure 1-b).

Figure. 1. a) Schematic structure of the textile goniometer sensor. The black stripes represent the two identical piezoresistive KPF layer, while the gray stripe represents the insulating layer. b) When the goniometer is flexed, the sensor output (ΔR) is proportional to the bending angle (θ), defined as the angle between the tangent planes to the sensor extremities. c) KPF goniometer electrical equivalent and block diagram of the front-end acquisition circuit. The high-input impedance stage is based on two instrumentation amplifiers (INS1 and INS2). DIFF is a differential amplifier. The output ΔV is proportional to ΔR and thus to $\Delta \theta$.

For the acquisition of ΔR from each of the three goniometers, we designed an ad hoc three-channel analog front-end circuit. For each sensing layer (represented as a series of three electrical resistances) of the KPF goniometers three pads were designed for sensor wiring (p_1 to p_3 for the top layer, p_4 to p_6 for the bottom layer). The idea is to use a four-point resistance measurement method to avoid the influence of cable connection into the sensor output evaluation.

The complete diagram of the acquisition circuit is reported in Figure 1 c). For each goniometer, the voltages $V_1 = V_{p2} - V_{p3}$ and $V_2 = V_{p5} - V_{p4}$ are measured between the internal pads when a constant and known current I is supplied through the external pads. A high input impedance stage, consisting of two instrumentation amplifiers (INS1 and INS2), measures the voltages across the KPF

sensors. These voltages are proportional, through the known current I , to the resistances of the top and bottom layers (R_1 and R_2). A third differential amplifier DIFF amplifies the difference between the measured voltages, obtaining the final output ΔV , which is proportional to ΔR and, thus, to the flexion angle θ . Each channel of the described front-end was analogically low pass filtered (anti-aliasing, cut-off frequency of 10 Hz). The resulting data were digitally converted (sample time of 100 Sa/s) and wirelessly transmitted to a remote PC for storage and further elaboration.

In previous study [5] was demonstrated that the KPF goniometers is a valuable instrument for joint angle monitoring with errors below 5 degrees compared to optical measurement system during natural hand opening/closing movements.

2.2 The Glove design

The sensing glove consists of three KPF goniometers directly integrated on the elastic lycra fabric.

Figure. 2 Sensing glove and its wireless acquisition unit.

For index and middle fingers, the KPF goniometers have been placed on the dorsal side of the hand in correspondence with each metacarpal-phalangeal joint to detect the flexion-extension movement. To capture the opposition of the thumb, the goniometer has been placed in correspondence of the trapezium-metacarpal and the metacarpal-phalangeal joints. This minimal sensor configuration - having a low number of monitored degrees of freedom - was conceived as a trade-off between a good grasping discrimination and design constraints typical of wearable and ambulatory applications. Indeed, the number of KPF goniometers has to be low to increase the wearability and the user comfort number (i.e. a single goniometer has six connecting wires as pointed out in previous study [5]). Despite the low number of goniometers, the observation of the basic hand grips pointed out the possibility of discriminating between them having information at least about thumb, index and medium finger position [2]. In addition, studies on hand synergies demonstrated that monitoring a low number of relevant joints allows an efficient grasping discrimination [4][7][3].

2.3 Characterization of Movements

Table 1 shows the movements selected to send commands to the collaborative robot.

Table 1. Defined Movements

N °	Initial Posture	Final Posture	Description	Command
1			From initial posture to final posture twice.	To center the camera surgeon's tool.
2			From initial posture to final posture twice.	To indicate a place to suture, cut, and so on.
3		-	Initial posture a defined time.	To indicate to stretch the thread.

Defined movements are realized faster than involuntary ones as it is shown in Figure 4. Rising and falling values correspond to finger-opening and finger-closing movements respectively. The developed algorithm uses threshold values to detect finger-movements.

The graphs of flexion and velocity for index and medium fingers obtained from the data of the sensing glove are shown in figures 3 and 4. When the movement 1 in Table 1 is performed, finger-closing and finger-opening are characterized respectively with the falling and rising lines in the graph..

Figure. 3 Data from sensing glove which are proportional to finger flexion angle θ in defined movements.

Figure. 4 Velocities in defined movements using the finger flexion data of Figure 3.

To obtain the parameters to define movement 1, $L_1 = \{x_1, v_1, t_1\}$, several samples of the same movement realized by the same person are analyzed. To obtain v_{1u} , which is the threshold to consider the movement, firstly, the average of the velocity along the descents and ascents is calculated. These periods are

represented as D1, A1, D2 and A2 in the Figure 5. The time t_{D1} is the time during D1.

Figure. 5 Data from sensing glove which are proportional to finger flexion angle θ in movement 1.

Figure. 6 Velocities in movement 1 using the finger flexion data of Figure 5.

These velocities determine the average of the movements of finger-opening and finger-closing.

The next step is to calculate the standard deviation for the above-mentioned movements.

The threshold value will be the minimum of the speeds thresholds obtained in every opening or closing.

t_{1u} will be defined by the minimal time in which is executed the D1, A1, D2 and A2 intervals.

The procedure to characterize index finger in movement 2 is the same as the explained above.

For the defined movement 3 we must consider an interval (a, b).in which the flexion values are approximately constant for a predefined time t_{3u} . This time is the minimum of the samples realized by the same person. The interval will be obtained in the same way as the speeds obtained in the movements 1 and 2.

2.4 Algorithm for the Movements Detection

The algorithm for the detection of the defined movements analyzes the velocities of the fingers which are in motion to detect if it can be considered a part of some of the movements.

To consider movement 1, index and medium must be in motion at a velocity upper than the threshold defined in the previous paragraph during a certain time and realize a moment of closing and opening two times.

The detection of the movement 2 is a similar procedure but considering that only the index finger is moving.

On the contrary, for the movement 3 the algorithm must detect that the values of the fingers index and middle are in a certain interval (a, b) during a time superior to the time of execution established with a null speed. All these characteristics are represented in Table 2.

Table 2. Characterization of Defined Movements

N °	Fingers	Velocities	Flexion Pattern	Time
1	Index Medium	$ V_e > V_{1u}$	D1 A1 D2 A2	$t_e < t_{1u}$
2	Index	$ V_e > V_{2u}$	D1 A1 D2 A2	$t_e < t_{2u}$
3	Index Medium	$ V_e = 0$	$\theta \in (a, b)$	$t_e > t_{3u}$

2.5 Experiments

The tests tried to prove that the gestures realized by the surgeon can be recognized.

Four different persons were asked to carry out the movements expressed in Table 3 in the same order in which they appear in the table, doing between them a flat position of the hand. This movements sequence has been executed three times for person.

Movements 4 and 5 has been introduced in order to test the algorithm. These movements are similar to movement 1 and 2 but there are small differences between them.

Table 3. Set of Test Movements

N °	Initial Posture	Final Posture
1
2
3		-
4
5

3. RESULTS

After the parameters were fitted to every person, the algorithm has recognized the movements defined in all the cases except in these represented in Figure 7 and Figure 8 for movement 2 and in Figure 9 and Figure 10 for movement 3. Movements 4 and 5 defined in Table 3 were not identified as movements 1 or 2.

Figure. 7 Data from sensing glove which are proportional to finger flexion angle θ in movement 2.

Figure. 8 Velocities in movement 2 using the finger flexion data of Figure. 7.

Figure. 9 Data from sensing glove which are proportional to finger flexion angle θ in movement 3.

Figure. 10 Velocities in movement 3 using the finger flexion data of Figure 9.

4. DISCUSSION

The experiments carried out with the glove show that the developed algorithm can robustly detect the three defined movements among a set of different continuous movements. Logically, to correctly identify the motion patterns of the movement executed by the surgeon the sequence must begin and finish with similar positions to those of the models and not include strange intermediate movements. The identification of the movements is accurate because the identification is not only based on the initial and final positions but also on the intermediate positions and velocities which are continuously analyzed to determine if their pattern is similar to that of the model. The obtained patterns using the smart glove present sufficient information to be robustly identified avoiding the errors in those situations where the positions are similar to those of the model but the execution speed of the movement is different.

5. CONCLUSION

In this article, a first system developed to robotize the Hand Assisted Laparoscopy Surgery (HALS) has been presented. This system is based on a glove with piezoresistive sensors that continuously capture the flexion degree of the surgeon fingers. The aim of this wearable is to identify commands that are given by the surgeon using his hand. This information will be sent to a collaborative robot during the operation. Patterns of flexion and velocity of the finger movements from the initial to the final positions are modeled in the algorithm to recognize the hand commands. The developed methodology has proved to be robust and effective in the identification of this set of considered movements.

6. ACKNOWLEDGMENTS

This research has been partially funded by the Spanish State Secretariat for Research, Development and Innovation, through project DPI2013-47196-C3-3-R.

7. REFERENCES

- [1] Atsushi Shiozaki, "Hand assisted technique beneficial for laparoscopic transhiatal esophagectomy with en bloc dissection of middle and lower mediastinal lymph nodes: roles of the operator's left hand". *Esophagus*, Volume 14, Issue 2, pp 138–14, April 2017.
- [2] Bianchi, M., Carbonaro, N., Battaglia, E., Lorussi, F., Bicchi, A., De Rossi, D., & Tognetti, A. "Exploiting hand kinematic synergies and wearable under-sensing for hand functional grasp recognition." In *Wireless Mobile Communication and Healthcare (Mobihealth)*, EAI 4th International Conference on (pp. 168-171). November 2014.
- [3] Bianchi, M., Haschke, R., Büscher, G., Ciotti, S., Carbonaro, N., & Tognetti, A. A Multi-Modal Sensing Glove for Human Manual-Interaction Studies. *Electronics*, 5(3), 42. 2016.
- [4] Bianchi, M., Salaris, P., Turco, A., Carbonaro, N., & Bicchi, A. "On the use of postural synergies to improve human hand pose reconstruction." In *Haptics Symposium (HAPTICS)*, IEEE (pp. 91-98). 2012.
- [5] Carbonaro N., Mura G. D., Lorussi F., Paradiso R., De Rossi D., Tognetti A. "Exploiting wearable goniometer technology for motion sensing gloves." *IEEE J. Biomed. Health Inform.* 18, 1788–1795.10.1109/JBHI.2014.2324293. 2014.
- [6] Carbonaro, N., et al. "Unobtrusive physiological and gesture wearable acquisition system: a preliminary study on behavioral and emotional correlations." *Global Health* : 88-92. 2012.
- [7] Ciotti, S., Battaglia, E., Carbonaro, N., Bicchi, A., Tognetti, A., & Bianchi, M. "A synergy-based optimally designed sensing glove for functional grasp recognition." *Sensors*, 16(6), 811. 2016.
- [8] Ding J., Xia Y., Liao G., Z. Zhang, S. Liu, Y. Zhang, and Z. Yan, "Hand-assisted laparoscopic surgery versus open surgery for colorectal disease: a systematic review and meta-analysis," *The American Journal of Surgery*, vol. 207, no. 1, pp. 109–119, 2014.
- [9] Dipietro, L., Sabatini, A.M., Dario, P. "A survey of glove-based systems and their applications", *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, 38:4, 2008, pp 461-482.
- [10] Gorey, T.F., Tierney, S., Buckley, D., O'Riordain, M., Fitzpatrick, J.M., "Video-assisted Nissen's fundoplication using a hand-access port", *Minimally Invasive Therapy and Allied Technologies*, 5 (4), pp. 364-366, 1996.
- [11] Harold J. Leraas, Cecilia T. Ong, Zhifei Sun, Mohamed A. Adam, Jina Kim, Brian F. Gilmore, Brian Ezekian, Uttara S. Nag, Christopher R. Mantyh, John Migaly1 "Hand-Assisted Laparoscopic Colectomy Improves Perioperative Outcomes Without Increasing Operative Time Compared to the Open Approach: a National Analysis of 8791 Patients", *J Gastrointest Surg*;21(4):684-69, April 2017 .
- [12] Lorussi, F., Carbonaro, N., De Rossi, D., Paradiso, R., Veltink, P., & Tognetti, A. "Wearable textile platform for assessing stroke patient treatment in daily life conditions". *Frontiers in bioengineering and biotechnology*, 4. 2016.
- [13] Lorussi, F., Carbonaro, N., De Rossi, D., & Tognetti, A. A bi-articular model for scapular-humeral rhythm reconstruction through data from wearable sensors. *Journal of neuroengineering and rehabilitation*, 13(1), 40. 2016.
- [14] Targarona, E.M., Gracia, E., Garriga, J., Martínez-Bru, C., Cortés, M., Boluda, R., Lerma, L., Trias, M., "Prospective randomized trial comparing conventional laparoscopic colectomy with hand-assisted laparoscopic colectomy: Applicability, immediate clinical outcome, inflammatory response, and cost", *Surgical Endoscopy and Other Interventional Techniques*, 16:2, 2002, pp. 234-239, 2002.
- [15] Tognetti, A., et al. "Daily-life monitoring of stroke survivors motor performance: The interaction sensing system." *Engineering in Medicine and Biology Society (EMBC)*, 36th Annual International Conference of the IEEE. IEEE, 2014.
- [16] Tognetti, A., Lorussi, F., Carbonaro, N., & de Rossi, D. Wearable goniometer and accelerometer sensory fusion for knee joint angle measurement in daily life. *Sensors*, 15(11), 28435-28455. 2015.
- [17] Tognetti A., Lorussi F., Mura G. D., Carbonaro N., Pacelli M., Paradiso R., et al. "New generation of wearable goniometers for motion capture systems." *J. Neuroeng. Rehabil.* 11, 56.10.1186/1743-0003-11-56, April 2014.
- [18] Proyecto BROCA. Available: <http://www.proyecto-broca.es> [Accessed 28 April 2017]
- [19] Da Vinci Surgery: Minimally Invasive Surgery. Available: <http://www.davincisurgery.com/> [Accessed 28 April 2017]