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Feasibility Study of Hand Motion Analysis by the Leap Motion Sensor

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Abstract

This paper presents the results of a feasibility study for the use of the infrared sensor LeapMotion for hands motion analysis in clinical evaluation. A system was developed to allow patients with muscular weakness to use this sensor. This system was used on 2 patients affected by spinal muscular atrophy. The results showed that the LeapMotion is not sufficiently robust or accurate for clinical assessment. In addition, the proposed system installation complicates the process. More trials with specific users and profiles should be realized to refine and improve those results.

Key words

Spinal muscular atrophy, Motor function measurement, LeapMotion, Motion Analysis

1. Introduction

Physiotherapists are demanding of simpler and affordable tools allowing them to improve movement analysis. They use at least 2 types of analysis each using its own tools:

- The assessment: this study uses standard and validated protocol whom purpose is to quantify the patient's capabilities at an instant « t ». An example of those protocol is the MFM (Measure of Motor Function) consisting of 32 items, each rated from 0 to 3 permitting to quantify and represent neuromuscular disease state and advance.
- The rehabilitation: this study aim is to train the patient to maintain or improve existing capacities. It consists on a range of exercises to be done on an extended period of time thus soliciting the patient's motivation. The performance of the rehabilitation can be evaluated with

assessment. In this case it is necessary to control the patient's movement to ensure the efficiency of the exercises and to not aggravate the capacities.

This article takes part in a bigger project aiming to improve clinical assessment methods. Using new technologies, it should enable and facilitate movements capture and analysis to provide assistance for physiotherapists. Objectives for the developed tools are (1) movements storing, (2) movement description and assistive information, (3) the possibility of an entertaining environment for the patient. All this should be done without complexifying or lengthen the MFM-protocol. This project focuses on children (6-18 years old) affected by Spinal Muscular Atrophy type 2 and 3 (SMA 2/3) and the MFM-protocol. This protocol cover the full length of the patient capacities from the weakest to the strongest by evaluating capacities from a lying position to a standing position and from proximal to distal motions. Tools used currently in this project are performants for mid and wide range motion allowing assessment for mid to strong patients. However for the weakness patient, only the small movements close to the body and hands motion remain. Thus it is necessary for those patients to find adapted technologies to capture and analysis those movements.

Some tools have been developed for hand analysis. They can be separated in 3 categories: robotics systems, magnetic / electromagnetic sensors and optic sensors. The more efficient and usable professionally are the robotics systems whom some are tested and validated on patient such as « MyoSet »[2]. Those are specialized structure to analyse a dedicated movement or strength such as the MoviPlate which counts the number of round-trip that a patient can made with a finger between 2 cylinders. The instrumented "clothes" (with electro-magnetic / magnetic sensors) such as "data gloves" [3][4] are likewise efficient. Those are glove equipped with high definition angular sensors that retransmit the full hand movement. However those robotic systems are heavily specialized and the data gloves are complex to use and uncomfortable. In addition those systems are generally expensive. The marker-less optical systems are not yet clinically validated but present numerous advantages: non-invasive and non-intrusive, they are adaptable to numerous situations and require minor instalment. Their main hardship [5] come from the complexity of the elements to be tracked and of the occlusion problems which can appear during a motion. Since 2012, a low-cost infrared sensors is available on the market (90$) allowing the tracking of a numerical skeleton of the hand: le Leap Motion [6]. This sensor seems a relevant addition to our project specifically since it does not require to install any marker on the subject, nor lengthy calibration. Additionally, it is possible to easily retransmit the information thanks to custom software into relevant information for the physiotherapists. Finally, its low-cost and accessibility make is coherent with the aim of the protocol to provide an assessment easy to administrate and easy to be put in place. It remains to verify if all hand positions possible for the patient can be identified with this device.

The LeapMotion [6] is an infrared sensor specialized in hand tracking. It allows the tracking of a numerical skeleton for each hands. The hand skeleton consists of the center of the hand and of the 5 fingers each divided into 4 points (the base of the finger then one point per phalanx extremity). It should be noted that a pen can be used as a pointer.

The emission frequency can go from 20 to 200 Hz depending on the record conditions. Each point consists of a position in mm in the 3 dimensions. Several manipulation advices are provided by the constructor of the LeapMotion. It notably indicates that the hand should balance 9 to 20 cm above the device, be centered on the sensor and the user should not lean on the sensor. Finally, the user should avoid to hold its hand or have a curled hand. It's on this last recommendation we will try to validate the LeapMotion capabilities for our weakest patient.

2. Leap Motion literature:

In order to facilitate LeapMotion application creation, some teams, such as Weichert et al [7] and Guna et al [8], studied the accuracy and robustness of such a tool. Weichert et al [7] have focused on the pointer detection. Using an industrial robot equipped with a pen, they found a static accuracy of 0.2 mm and a dynamic accuracy of 1.2 mm for the pointer mode. Guna et al [8] realized a comparison between the hand tracking mode of the LeapMotion and the tracking system Qualysis. For static measure they equipped a prosthetic hand with a passive marker. For dynamic measure they used 2 sticks equipped with passives markers to represents 2 fingers. They demonstrated an accuracy lower than 0.5mm in static but warned that obtaining tracking stability was challenging. Peak of detection was obtained when the hand was visible (open and +/- parallel with the plan) and well above the LeapMotion, preferable a little in front of the LeapMotion. Dynamic accuracy was significantly less. Starting from this numerous applications, others experiments were developed : augmented-reality applications [9] whose purpose were to use our hand to manipulate and explore an environment or an object and were proven to be easy to use. Applications for sign language recognition[10]. They noted good potential but were faced with occlusion difficulties. Other applications were to manipulate an industrial or domestic robot [11][12]. Liu et Zhang [12] managed to effectively track the movement of a welder and reproduce it programmatically with an arm robot. Finally authors proposed applications in the hand rehabilitation [13][14] : Khademi et al [13] have diverted the game « Fruit Ninja » to train the hand of stroke patients and observed a good correlation between the game score and the Fugl-Meyer assessment scale. Iosa et al [14] also proposed a rehabilitation serious game for older people. They observed an augmentation of participation on the Pittsburgh participation scale thank to this device.

The study aim to determine if the LeapMotion [6] can be used to realize a finger motion analysis in the contact of physiotherapist's examination. The MFM [15] includes 5 items designed to evaluate the strength and distal accuracy of fingers. For this study, item compatible with the LeapMotion was selected: the item 18 whom aim is to trace the contour of a CD resting on a table. It is a pointer exercise in which the LeapMotion seems relatively performant. This item is easily realized by mid and strong patient, it now should be verify with the weakest patients.

3. Method

A system allowing the tracking of the finger for the item 18 is established with the LeapMotion. It was then used with 4 subjects: 2 type 2 SMA patients and 2 healthy control subjects.

3.1. Exercise description and requirements

The patient should be positioned in a sitting posture. Forearm should be relaxing on a table or a support with elbow at approximatively 90° (nimble shoulders). The subject has to trace the contour of a CD with its finger. Depending of its capacities, 2 circles are possible: the interior of the CD with a diameter of 3.5 cm and the exterior of the CD with a diameter of 12 cm. The finger used can be chosen by the subject and the exercise start with the chosen finger at the center of the CD.

3.2. Experimental requirements and equipment

To use the LeapMotion, the users have to maintain their forearm and hand balanced 9-20 cm above the device. In our context, the users are patients with limited physical capabilities which make this position unattainable, moreover the exercise have to be done on a support like a table for example. It is then necessary to provide an adapted environment allowing an ergonomic posture in adequacy with the MFM's exercise. The LeapMotion uses an infrared technology, this lead to the proposition of a Plexiglas support, allowing the user to place their arms but letting pass the infrared ray. This support was fabricated with a laser-cut machine. In addition the CD required by the exercise and described in part A were also engraved on this table (Figure 1.a).

The Leap should then be maintained 9-20cm below this Plexiglas support. For this, 2 systems are proposed and tested:

1. Use the adjustable table of physiotherapists and install the Plexiglas table above it with 4 studs. The LeapMotion resting in the lower table. However this technique of a « double-table » is not always possible with wheelchairs.
2. Hang the LeapMotion under the support with a thread and a 3D printed support to keep the sensor steady at a defined distance. This solution is adaptable to all type of patient's wheelchair (Figure 1.c).

Hand data are then recorded with a custom C# software: the recorded data are consisting of all the 3D points of the right and Left hand tracked by the LeapMotion. Those data are recoded in text files to be analyzed by the calculus software Scilab.

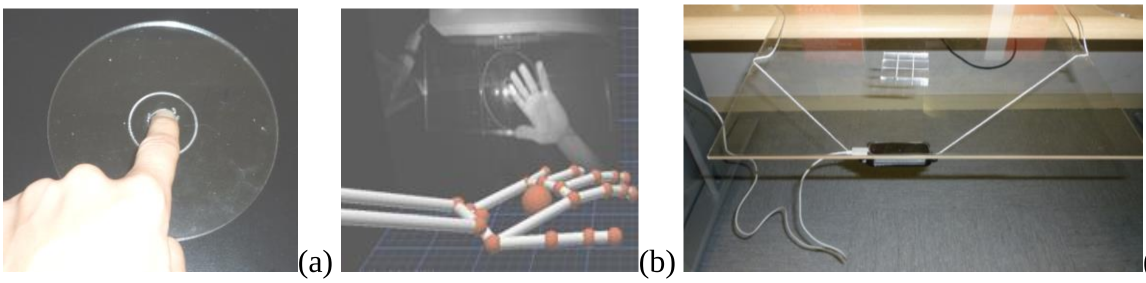
(a) (b) (c)

Figure 1: (a) Plexiglas CD (b) Detection across the support (c) Leap is suspended under the Plexiglas support

Prelaminar trials were realized to testify the good detection by LeapMotion even with a Plexiglas support (Figure 1.b). It turned out that the system works correctly in this context (with the addition of a Plexiglas table between the user and sensor).

To verify if the detection is reliable, prelaminar trials were realized with the help of 4 adults (39-68 years old) and 2 children (5-7 years old). Each subject has done the contour of the large and small CD. Different "types" of hand were tested: an open-hand (hand is horizontal and parallel with the support, fingers are exaggeratedly outstretched and spaced), a natural-hand (hand parallel with the support with the finger in "comfortable" position) and the closed hand (hand in a fist position with just the index extended). The results are presented below (cf. table 1 and 2).

Thoses results are coherent with literature. Closed-hand are harder to see than natural or open-hand. There is little difference between open hand and natural-hand. Finally it can be noted that smaller hands are more difficult to track and are less accurate than adults' hands. Those trials also highlighted the necessity of constant movement met by Guna et al. [8] : a static hand will maintain its detection only for a short moment, if the hand does not move the tracking will fail. Finally it can be noted that at first sight those values seem quite inaccurate but this will be discussed below in the discussion part of this paper.

Table 1: Prelaminar results

	Mean Error (mm)	*Deviation (mm)*
Global	12,2	9,5
Large CD	14,3	7,2
Small CD	10,5	11,4

Table 2: Prelaminar results by conditions

	Mean Error (mm)	*Deviation (mm)*
Adults	12,5	7,1
Children	13,4	12,3
Open-Hand	11,0	9,6
Natural-Hand	13,6	9,2
Closed-Hand	20,9	16,3

3.3. Patients description

The first patient, Subject A, was an adult with a type 2 SMA. He conserved a little trunk mobility and a mobility in its hand (he can lift its palm hand maintain it in support on its finger). However, its capacities only allow him to trace the contour of the small CD.

The second patient, Subject B, was a teenager affected by a type 2 SMA. He cannot hold its trunk (he is in corset) and has a lower hand capacities compared to subject A. However its capacities allow him to at least trace the smaller CD. The 2 control subjects presented no motor difficulties and also realized the trials.

4. Results

4.1. Control subjects

The Figure 2.1 show examples of finger motion tracked for healthy subjects. The tracking was simple and do not needed any adaptation or any signal treatment.

4.2. Subject A

The Figure 2.2 (a) and (b) show examples of finger motion tracked by the sensor for a patient A attempting the small contour CD.

Those results were gained after several trials due to the difficulties to maintain a steady tracking of the hand. The movement of the hand almost always generate a failure of the tracking when initialize was achieved. Numerous instantaneous failures were observed during the exercise making the measurement inaccurate (Figure 2.2a). The only full contours recorded were achieved by imposing the use of the major finger (non-natural). Indeed, this situation allowed the hand to be opened (not in a fist or fist-like position) during the whole exercise (Figure 2.2b).

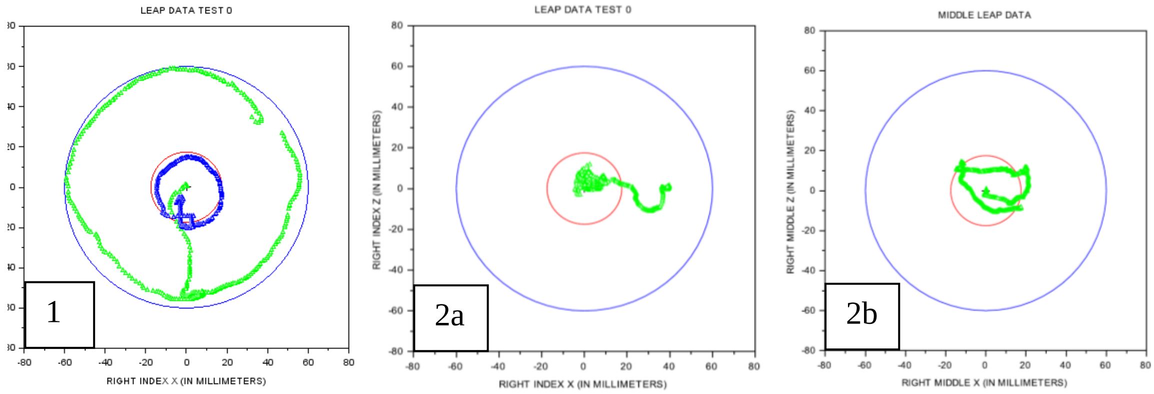

Fig 2: (1) Control subject (blue) Small CD contour (green) Large CD contour (2) SMA subject A (a) Test with index (b) Test with major

4.3. Subject B

The initial detection of the patient's hand turned out to be very challenging for the LeapMotion (Figure 3). Moreover, as soon as a movement was initiated the tracking was failing. No measure was available. The problems appearing during the tracking can be from several sources: a small hand, a closed hand, an arm close to the trunk which allow low compatibility with the LeapMotion.

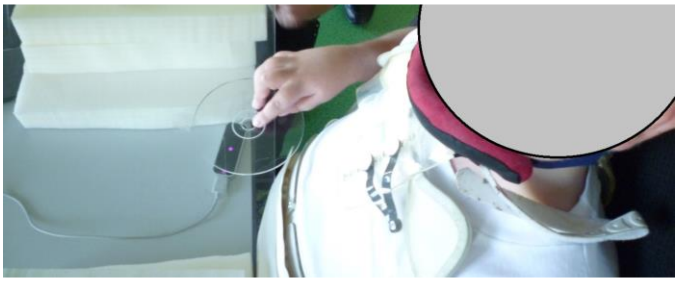

Fig 3: Installation of the LeapMotion for an SMA patient

5. Discussion

Those experiments' results illustrate several points. The LeapMotion can be used with a Plexiglas support to provide arms' rest. Engraving on this Plexiglas support may generate infrared concentration zones. In addition the global accuracy of the LeapMotion decrease with the diffraction effect of this support.

The prelaminar tests were realized to verify the good functioning of the LeapMotion with the Plexiglas support when the subject performs the item 18. The mean error from the norm circle are important but can be explained by several ways. The subject begun at the CD center then have to go around the CD, he then reflexively go back at the center of the CD (cf. Figure 4.b). This comeback at the center is assimilated in the error but is not representative of the exercise. Another reflex is to remove its hand while the record was not ended (cf. Figure 4.a). Again, this movement is assimilated in the error but should not be considered.

Thus, it was proposed to remove those reflexive movements which are none representative of the exercise. The results of the cleaned data are presented on the tables 3 and 4 below (in brackets, the original data). With cleaned data, an amelioration of the accuracy is observed. The rest of the lack accuracy come from the inaccuracy of the system (LeapMotion error and Plexiglas diffraction), but also from the ways to go around the CD. Indeed when the subject realized the contour of the CD, he will use the whole surface of its phalanx extremity and not its exact extremity. Thus there is naturally a little displacement of the extremity used. It can be noted that the cleaned data show a smaller difference between adults and children accuracy. Finally it can be noted that the difference between open-hand and natural-hand is this time notable. On contrary the closed-hand position maintain its important error.

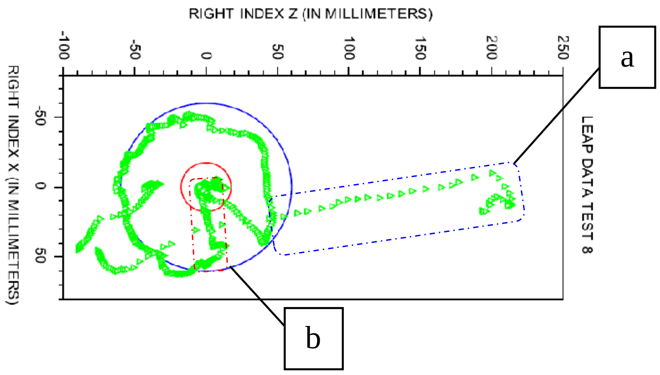

Fig 4: Tracked data example

Table 3: Preliminar results

	Mean Error (mm)	*Deviation (mm)*
Global	10,2 (12,2)	6,8 (9,5)
Large CD	11,9 (14,3)	5,8 (7,2)
Small CD	8,4 (10,5)	7,6 (11,4)

Table 4: Preliminar results by conditions

	Mean Error (mm)	*Deviation (mm)*
Adults	10,4 (12,5)	6,0 (7,1)
Children	10,7 (13,4)	7,5 (12,3)
Open Hand	8,6 (11)	5,6 (9,6)
Natural Hand	10,7 (13,6)	6,9 (9,2)
Closed Hand	19,6 (20,9)	12,1(16,3)

To ensure an initial tracking of the hand by the LeapMotion, the fingers have to be clearly visible and spaced. Hand should not touch each other’s and the hand posture with a « broken wrist » is not recommended. Thus, a good tracking can only be achieved with hand clearly visible, or at least natural, hand in front and above of the sensor. Several trials with the LeapMotion above the hand were realized but did not achieved better results. In addition to maintain a tracking, a movement should regularly be observed, thus wide and fluid motion are advised. Those conditions are hardly possible for those pathologies.

Those observations put in evidence the gap between the healthy and the pathological population. It is possible for a healthy population to measure the movement with the LeapMotion and a Plexiglas support. Measurement are coherent and analysable even if additional trials are needed to characterize the optimal conditions for tracking with this support. The weakest pathological population is rarely able to maintain those condition or just necessaries condition for a LeapMotion tracking. The finger's retraction and their weak muscular strength imply low natural movements and thus undetectable movements for the LeapMotion. It is possible to enforce oneself to realize the movement in functional condition. For example, they can use their major when they would naturally use the index and thus achieved a correct tracking even if less accurate than a healthy population. However this type of directive are in contradiction with the purpose of the physiotherapists exercise : the patient should be able to do what is the more natural for him and is more in phase with his maximum of potential. The lack of accuracy and the impossibility of tracking people with limited movement make this use difficult. If the tool can probably be used with patient lightly or mildly affected, the weakest patient will not be visible which limit its usability.

Finally, besides the current problems or successes in measurement, the installations can be a challenge in itself. In fact, the positioning complexity of the Plexiglas support and the LeapMotion for patients in wheelchair can be difficult and even constraining for an everyday clinical use. Despite all this, one main advantage of the LeapMotion is its non-invasive and non-intrusive aspect of the tracking. However this advantage is reflected on a greater difficulties of installation and of use that can be tricky and long and require to understand how the sensor works to ensure correct measurements.

Conclusion

The LeapMotion, even if promising in the conditions described in this article, is currently insufficiently accurate and robust for actual application in the context of medical analysis with the MFM-protocol. In addition, our context makes the use of this tool little practicable even complex: if the use of Plexiglas is possible, the complexity to make this tool usable is such that it discards all potential.

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