Hand Tracking as a Tool to Quantify Carpal Tunnel Syndrome Preventive Exercises

Alvaro Uribe-Quevedo*†, Saskia Ortiz†, David Rojas‡, and Bill Kapralos§
*The Games Institute, University of Waterloo, Waterloo, Ontario, Canada, Email: ajuribequevedo@uwaterloo.ca
† Mechatronics Engineering, Mil. Nueva Granada University, Bogota, Colombia, Email: u1801858@unimilitar.edu.co
‡The Wilson Centre, Toronto, Ontario, Canada, Email: david.rojas@mail.utoronto.ca
§University of Ontario Institute of Technology, Oshawa, Ontario, Canada, Email: bill.kapralos@uoit.ca

***Abstract*—Various professions have an increased rate of carpal tunnel syndrome (CTS) given the reliance on regular and repetitive movements of the hand and wrist. With the widespread use of computing devices, the popularity of video games, and the ubiquitous nature of mobile devices, the occurrence of CTS is increasing amongst the general public. Given the rise in CTS along with the corresponding implications including reduced workplace productivity and the reduction in the quality of life, there is significant interest in devising effective interventions to prevent CTS. Non-intrusive approaches include various hand stretching-based exercises that have shown to be effective. However, as with any exercise program, motivation to continue the program quickly decreases. Here we describe a hand motion tracking approach coupled with an engaging game-based 3D user interface (3DUI) to promote hand stretching exercises. The hand stretching exercises are tracked and feedback is provided to the user regarding the motions thus, ultimately helping the users to perform the exercise correctly. Preliminary results indicate that the system can be used to promote hand exercises in a fun, and engaging manner.**

I. Introduction

Carpal tunnel syndrome (CTS) is a common disorder that causes pain due to the compression of the median nerve as it passes from the wrist to the hand. CTS is commonly diagnosed through the reporting of symptoms by patients, physical examination, and electrophysiologic testing. CTS can be caused by diabetes, thyroid disorders, alcohol use, arthritis, genetic predisposition, and occupational factors [1]. Work-related CTS occurs when routine activities require the regular and repetitive movements of the hand and wrist. It is not surprising therefore that CTS is most common in garment workers, butchers, grocery checkers, electronics assembly, workers, musicians, carpenters, and typists who are constantly performing repetitive hand movements [1]. With the widespread use of computing devices, the popularity of video games and ubiquitous nature of mobile devices, the occurrence of CTS amongst the general public is rapidly increasing [2] [3] [4] [5]. CTS can have a significant impact on the health and productivity of workers leading to a decrease in the quality of life, it can also lead to increased work-related absenteeism in both male and female workers alike [6]. This sharp increase of CTS along with its potential implications on worker productivity has led to increased interest in the development of effective interventions through engineering, administrative, personal or mixed approaches to prevent CTS [7].

Human factors and ergonomics can potentially play an important role in limiting the apparition of CTS. The human-centred design has resulted in the manufacturing of ergonomic keyboards and mice, wrist and palm support systems, followed by constant redesigns over the years. However, as Lincoln et al. state, various studies have failed to conclusively demonstrate that ergonomic design intervention has a primary impact on CTS prevention and acknowledge its influence as a high-risk factor to develop it [7]. Once CTS has developed and the symptoms are present, personal interventions based on exercise, training, wrist splints, and injections of anti-inflammatory steroids are some of the non-surgical treatments to control and keep the pain manageable. When the pain becomes chronic and the symptoms are unbearable, surgery is the dominant treatment. However, the effectiveness of a surgical intervention depends on various factors (e.g., how long the patient had CTS), and not necessarily on the surgical procedure itself [8].

With respect to exercise-based interventions, various stretching exercises are available which have been designed by carefully considering the pathogenesis and pathophysiology of CTS. It is hypothesised that stretching may relieve the compression along with improved postures and blood circulation [9]. Various studies have compared different types of non-surgical treatments. For example, Akalin et al. found that there was no statistically significant difference between patients using a volar wrist splint and those instructed to perform a series of tendon gliding exercises [10]. Rozmaryn et al. presented a study regarding the effectiveness of traditional preventive CTS exercises comprised of five discrete finger positions (fist, hook, straight, tabletop, and straight fist), with additional hand positions (neutral wrist with finger and thumb flexion neutral wrist and extended fingers and thumb; extended wrist and fingers while neutral thumb; wrist, thumb, and fingers extended combined with pronation or supination), all of which were held for seven seconds and repeated several times [11]. A study that examined the effectiveness of the approach revealed that only 43% of the participants who followed the preventive exercises required surgery to treat their CTS in contrast to 71.2% of the participants who required surgery within the group that who did not follow any preventive exercises [11].

Despite the benefits shown by an exercise-based intervention, enforcement and supervision of exercise execution is a limitation. As a result, when considering the workplace, exercise interventions, and most notably preventive exercise interventions are typically designed to be performed by the employee without any supervision. However, there are several challenges for an employee to overcome before an exercise intervention is effective, including a lack of motivation, lack of knowledge, lack of time, and lack of feedback. This, in conjunction with unclear guidelines, leaves the employee alone without sufficient resources. These challenges can be addressed through virtual interactive environments and games that are able to better motivate and engage the user while providing them feedback dynamically [12].

Here we present a cost-effective hand motion tracking approach that employs a Leap Motion controller, coupled with a, engaging game-based 3D graphical user interface (3DUI). The goal of this work is to explore the Leap Motion capabilities and its suitability as a complementary hand-stretching tool that is able to track a user's hand exercise motions and provide them with feedback regarding these motions thus ultimately helping them perform the exercise correctly.

II. Hand Tracking App Development

The human hand plays an important function in our daily activities allowing us to interact with our environment [13]. Through its anatomy, we are able to perform prehensile and nonprehensile tasks involving different power and precision grasps with varying geometries and levels of contact [14]. Afflictions to the hand can result in a loss of movement that can subsequently affect task execution and the quality of life due to the changes in force, grip, and dexterity among others [15]. The human hand possesses 22 degrees of freedom (DOF) (including the fingers) that allow performing various grasps and tasks through rotations at each joint resulting in flexion/extension, adduction/abduction, and radial/ulnar deviations [14].

A. Stretching Exercise Analysis

Participating in daily exercise activities is widely advised by experts to minimise the risk of musculoskeletal disorders of the hand. Exercise helps maintain muscles, tendons and joints in healthy and minimises the risk of suffering from musculoskeletal disorders [1]. Hand-based exercises can focus on stretching the hand or the fingers and their goal is to reach the greatest range of movement[2,3] [16]. Hand gliding exercises include fist, hook, straight, tabletop, and straight fist, while stretching exercises include neutral wrist with finger and thumb flexion neutral wrist and extended fingers and thumb; extended wrist and fingers while neutral thumb; wrist, thumb, and fingers extended combined with pronation or supination. Figure 1 illustrates some of these exercises.

[1]Rehabilitation Exercise and Conditioning Handouts: orthoinfo.org/topic.cfm?topic=A00672

[2]Carpal Tunnel Syndrome Exercises: www.eatonhand.com/hw/exercise.htm

[3]Hand Gliding Exercises: www.orthonc.com/sites/default/files/forms/physical_therapy/homeex/Tendon_Gliding_Exercises_Hand.pdf

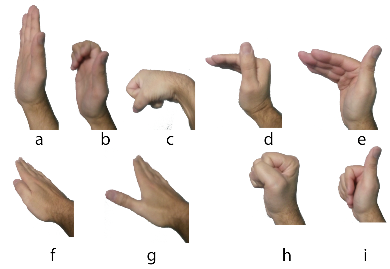

Fig. 1. CTS hand gliding and stretching sample exercises. a) Neutral wrist with extended fingers and thumb, b) hook fist, c) flexion fist, d) extended arm with fingers and palm bend, e) tabletop, f) straight palm, g) straight with extended thumb, h) closed fist, and i) straight fist.

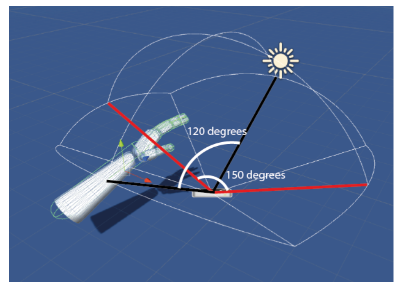

Fig. 2. Sensor tracking volume.

B. Motion Tracking

The Leap Motion[4] consists of three infra-light emitters and two infra-red cameras to estimate depth. The sensor is aimed at tracking human hands and fingers for gesture and finger-based interactions. An analysis of the sensor presented by Weichert et al. establishes that it is not possible to achieve the accuracy of 0.01 mm stated by the manufacturer [17]. This claim was supported by using tool tracking and reproducing the motion-captured data on an industrial robot with 0.2 mm resolution. In this situation, the LeapMotion sensor was only able to track at 0.7 mm. However, if tracking a static object, accuracy below 0.5 mm can be obtainable [18]. The sensor has a tracking area of 609.6 mm on each side and above as presented in Fig. 2[5]. Within this volume, the sensor detects the position and orientation of each finger, in addition to the hand with a projection of the forearm.

Given the optical sensing performed by the Leap Motion's IR cameras, the Leap Motion lacks the ability to track the full hand and it can easily lose track of the hand and fingers if they are not visible. This limitation reduces the possible scenarios that the Leap Motion controller can be applied to. In the case of hand exercises, the LeapMotion cannot properly detect the positions of the fingers in all of the fist exercises (full, straight and hook). This was expected as the sensor loses visibility of the fingers, and position estimation through kinematics does not provide accurate enough data. Figure 3 illustrates the hand exercises as viewed through the Leap Motion cameras.

[4]www.leapmotion.com

[5]How does the Leap Motion Controller Work: blog.leapmotion.com/hardware-to-software-how-does-the-leap-motion-controller-work/

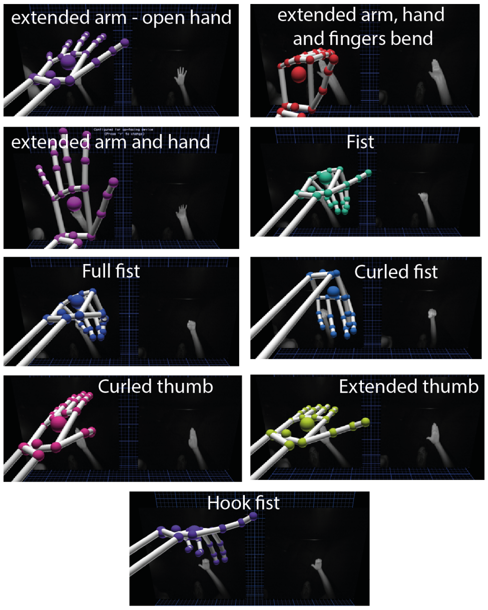

Fig. 3. Exercises seen from the LeapMotion.

C. Exercise Tool Development

Anatomical features and sensor constraints were considered in the development of the hand monitoring tool based on the exercises to prevent CTS within a computer-based (typing) environment [1]. To develop the interactive virtual environment, Unity3D[6] was chosen given its properties and multi-platform building capabilities. To integrate the Leap Motion controller with Unity3D, Leap Motion provides an SDK[7] that contains assets which allow programming interactions based on the motion tracked data.

The graphical user interface (GUI) provides instructions in a manner similar to traditional exercise guides and employs 3D model animations to demonstrate how the movement is expected to be performed. However, to address the self-guided and subjective assessment challenges resulting from not having a physician monitoring the exercise, the LeapMotion controller can serve as the monitoring tool. Through the tracked motion data, the application provides information regarding the range of motion and rotation of the hand and fingers.

D. System Overview

The main menu allows the user to choose the exercise (the exercise to be performed can be configured as instructed by a physician/exercise expert), visit links of interest and quit the application. Once the exercise is chosen, instructions are presented to the user, and a timer begins. Visual feedback regarding the movement of each hand is provided in two forms: i) two objects indicating a well-performed movement or position with green colour, poorly performed movement with yellow colour and badly performed movement with red colour, and ii) a plot chart showing the movement of the part of interest.

[6]www.unity3d.com

[7]Getting started with Unity and LeapMotiondeveloper.leapmotion.com/getting-started/unity

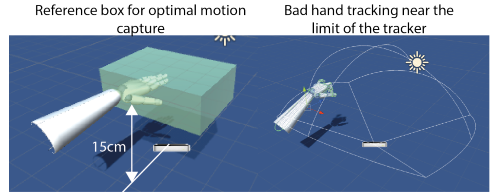

Fig. 4. Hand position optimal tracking placement and lost hand tracking.

Fig. 5. Orientation validation with a ruler in 0 degrees and 70 degrees extended.

The tracking environment must be configured in a manner that guarantees proper data collection. The first consideration is the hand's position above the sensor. Given the motion tracking area, it is easy for a user's hand to exit the optimal range where the sensor best tracks the hand. To avoid such a scenario, once the exercise starts, the user is required to position his/her hands within a virtual box located 15 cm from the sensor and with hands separated by a distance equal to two times the user's thumb length as illustrated in Fig. 4.

To measure the flexion and extension rotations of the hand, the data from the tracker had to be readjusted as the Leap Motion controller asset measures palm orientation starting from 0 degrees with the palm facing the sensor, and if the hand curls the sensor measures the angles below 360 degrees. However, this is not how the hand's range of motion is measured. More specifically, the neutral position of the hand is equal to 0 degrees and when extended will reach 60 degrees and when fully curled reaches -60 degrees. It is worth noting that these limits may vary as tendon and ligament properties may result in lower or higher ranges of rotation depending on each person [19]. To validate the adjustment, an angle finder rule was used to compare hand rotations with data tracked with the sensor, which resulted in an appropriate measurement with a variation of two degrees.

Angle measurement can vary due to various factors including: i) under or overexposure to light sources, ii) poorly aligned sensor with respect to the screen, iii) sensor placed over an uneven surface, and iv) arm and forearm rotations. This last one is important to consider as the sensor projects a virtual forearm and it is from this virtual forearm that hand rotations are calculated, and therefore, a partially extended forearm changes the tracked angles of the hand. With these considerations, the software we developed provided instructions as follows: i) check the position of your hands within the green box, ii) the blocks will change colours whereby green = good, yellow = poor, and red = bad, iii) extend and

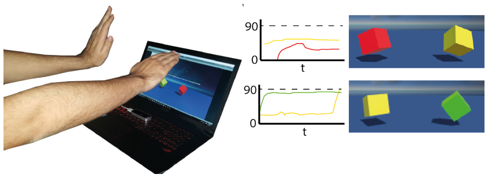

Fig. 6. Hand extension exercise motion capture test.

Fig. 7. Duck swiming exergame.

stretch both wrists and fingers acutely as if they are in a handstand position, and iv) perform the exercise. Fig. 6 provides a sample of the motion capture where two cubes provide visual feedback through colours regarding the execution of the exercise. Feedback regarding the range of motion was also possible to visualise through curves displayed on the upper left corner of the graphics user interface.

III. Results

To examine the feasibility of the hand motion capture methodology described here as a suitable tool for monitoring CTS-based exercises, an exergame was developed with an interactive scenario. The exergame requires the user to control the navigation of a duck through the propelling movement of the duck's legs. Each leg is controlled by flexion/extension movements mapped from the player's hand motions (captured with the Leap Motion controller). To provide context and avoid having meaningless repetitions, the player is required to navigate through checkpoints that allow replenishing of energy. The goal is to find other fellow ducks and bring them together at the other side of the lake as presented in Fig. 7. The user obtains visual feedback from the duck's moving legs and other elements in the scene such as: i) other ducks, ii) ranges of motion, iii) time, and iv) energy expenditure to have the user focused on the game and not the exercises. However, it is important to notice that to control the duck, proper hand movements are required as specified by the health care specialist.

Finally, to analyse the interest and potential impact of our approach, a preliminary experiment was conducted with seven participants, all of whom where fourth-year engineering students (ages between 21 and 23). Participants demographics showed us that all of them spend over eight hours using computer keyboards daily. Participants used the cube application and played the duck exergame for a period of time (2 minutes) and afterwards, they were asked to complete a questionnaire that gauged their experience.

All of the participants found the use of the Leap Motion controller to be interesting given its multiple uses as a user interface. All participants agreed that the duck exergame was more exciting (than the cube application) and provided recommendations to improve the cube application (i.e., providing interactions with the virtual environment as a result of hand movements). After using the developed tool, participants' awareness of the range of motions of their own hands increased. The hand motion data helped participants realise that different people will most likely have different amplitudes of rotation. The captured data can help track the hand physical activity so it can be later assessed by a health care provider.

IV. Conclusion

In this work, we presented an approach that employs an affordable motion capture optic sensor (the Leap Motion controller) to quantify CTS preventive exercises. By analysing the sensor capabilities through a series of preliminary experiments (two test scenarios), we concluded that the device provided reliable motion capture data for hand and opposing finger stretches. However, fist-like exercises can be only assessed partially (i.e., whether the hand is open or closed). Individual finger monitoring is not accurately possible as the leap Motion controller's cameras cannot follow the fingers once they are curled. As a result, depth information is not attainable by the Leap Motion controller. From our initial exploration, feedback provides an aspect that requires further analysis, especially in cases where self-guided exercises need to be performed. From observing participants using the application and their responses to the preliminary experiment questionnaire we can obtain two conclusions. First, that the use of interactive scenarios can capture the attention of a user; and second, that exergames are preferred given their ability to provide an engaging environment where users can compete against each other and aim for the highest score.

Future works will focus on implementing a kinematics model to improve fist tracking, and implementing further exercises. We will also conduct a more thorough study regarding the effects of exercising with our approach and the usefulness of the motion tracked data for medical purposes within a follow-up assessment.

Acknowledgment

The authors acknowledge the support of the Mil. Nueva Granadas Virtual Reality Center, and the *Social Sciences and Humanities Research Council of Canada* in support of the IMMERSe research network.

References

[1] E. L. Baker and R. L. Ehrenberg, "Preventing the work-related carpal tunnel syndrome: physician reporting and diagnostic criteria," *Annals of Internal Medicine*, vol. 112, no. 5, pp. 317–319, 1990.

[2] E. Erkol İnal, K. Demirci, A. Çetintürk, M. Akgönül, and S. Savaş, "Effects of smartphone overuse on hand function, pinch strength, and the median nerve," *Muscle & Nerve*, 2015.

[3] Z. Mediouni, A. de Roquemaurel, C. Dumontier, B. Becour, H. Garrabe, Y. Roquelaure, and A. Descatha, "Is carpal tunnel syndrome related to computer exposure at work? a review and meta-analysis," *Journal of Occupational and Environmental Medicine*, vol. 56, no. 2, pp. 204–208, 2014.

[4] M. Fagarasanu and S. Kumar, "Carpal tunnel syndrome due to keyboarding and mouse tasks: a review," *International Journal of Industrial Ergonomics*, vol. 31, no. 2, pp. 119–136, 2003.

[5] D. Macgregor, "Nintendonitis? a case report of repetitive strain injury in a child as a result of playing computer games," *Scottish Medical Journal*, vol. 45, no. 5, pp. 150–150, 2000.

[6] M. McDiarmid, M. Oliver, J. Ruser, and P. Gucer, "Male and female rate differences in carpal tunnel syndrome injuries: personal attributes or job tasks?" *Environmental Research*, vol. 83, no. 1, pp. 23–32, 2000.

[7] A. E. Lincoln, J. S. Vernick, S. Ogaitis, G. S. Smith, C. S. Mitchell, and J. Agnew, "Interventions for the primary prevention of work-related carpal tunnel syndrome," *American Journal of Preventive Medicine*, vol. 18, no. 4, pp. 37–50, 2000.

[8] F. DeStefano, D. L. Nordstrom, and R. A. Vierkant, "Long-term symptom outcomes of carpal tunnel syndrome and its treatment," *The Journal of Hand Surgery*, vol. 22, no. 2, pp. 200–210, 1997.

[9] D. O'Connor, S. C. Marshall, N. Massy-Westropp, and V. Pitt, "Nonsurgical treatment (other than steroid injection) for carpal tunnel syndrome," *The Cochrane Library*, 2003.

[10] E. Akalin, Ö. El, Ö. Peker, Ö. Senocak, S. Tamci, S. Gülbahar, R. Çakmur, and S. Öncel, "Treatment of carpal tunnel syndrome with nerve and tendon gliding exercises," *American Journal of Physical Medicine & Rehabilitation*, vol. 81, no. 2, pp. 108–113, 2002.

[11] L. M. Rozmaryn, S. Dovelle, E. R. Rothman, K. Gorman, K. M. Olvey, and J. J. Bartko, "Nerve and tendon gliding exercises and the conservative management of carpal tunnel syndrome," *Journal of Hand Therapy*, vol. 11, no. 3, pp. 171–179, 1998.

[12] G. Burdea, "Keynote address: Virtual rehabilitation-benefits and challenges," in *1st International Workshop on Virtual Reality Rehabilitation (Mental Health, Neurological, Physical, Vocational) VRMHR*, 2002, pp. 1–11.

[13] L. A. Jones and S. J. Lederman, *Human hand function*. Oxford University Press, 2006.

[14] J. R. Napier, "The prehensile movements of the human hand," *Journal of Bone and Joint Surgery*, vol. 38, no. 4, pp. 902–913, 1956.

[15] M. Jäger, U. Steinberg, and B. für Arbeitsschutz, *Preventing musculoskeletal disorders in the workplace, Protecting Workers Health Series No 5*. World Health Organization, 2003.

[16] M. A. Wehbé, "Tendon gliding exercises," *American Journal of Occupational Therapy*, vol. 41, no. 3, pp. 164–167, 1987.

[17] F. Weichert, D. Bachmann, B. Rudak, and D. Fisseler, "Analysis of the accuracy and robustness of the leap motion controller," *Sensors*, vol. 13, no. 5, pp. 6380–6393, 2013.

[18] J. Guna, G. Jakus, M. Pogačnik, S. Tomažič, and J. Sodnik, "An analysis of the precision and reliability of the leap motion sensor and its suitability for static and dynamic tracking," *Sensors*, vol. 14, no. 2, pp. 3702–3720, 2014.

[19] J. Ryu, W. Cooney, L. J. Askew, K. An, and E. Chao, "Functional ranges of motion of the wrist joint," *The Journal of Hand Surgery*, vol. 16, no. 3, pp. 409–419, 1991.