Comparative study of Wearable Devices for Detection, Diagnosis and Rehabilitation of carpal Tunnel Syndrome

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Abstract: This comparative study paper summarizes the recent development in area of the hand wearable electronic devices for the rehabilitation and monitoring of the carpal tunnel syndrome. These devices mainly focus on the hand wearable system to supervise the posture and working pattern of repetitive hand movements during performing tasks on computer or other devices. This study main summarizes criteria is the application of electronic systems working for assessment rather than growth of new wearable sensor systems. There is a brief explanation about the biosensors sensors and data acquisition technology that benefits researchers to instrument wearable systems. A detailed description of various methods of evaluation for CTS is explained for application of wearable technologies. This system can be implemented in various areas like health and wellbeing, care, homebased therapy, valuation of treatment usefulness, and early sighting of disorders. A system can be developed by combining wearables with sensors to achieve home monitoring of humans and subjects with risky circumstances. Forthcoming works mandatory to development the system to clinical disposition of biosensors.

Keywords: Carpal tunnel syndrome, Orthosis, inertial, Prevention, Work-related musculoskeletal disorders, Muscular fatigue, Rutgers Master, Tele-rehabilitation

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1. Introduction

Today's era of technology increases the use of computer devices like laptop, desktop and mobiles. This will lead to medical problems due to repetitive posture for a long duration. To reduce health problems related to computer devices, wearable technology is expected to become an indispensable part of our life. This paper is about two parts of study. The first one is about the posture and movement of subjects during working time using wearable systems based on specification, application in health, textile area and hand wearable consumer electronics. The second one is about how hand wearable technology detects harmful repetitive motion that can cause critical disorders. Wearable system technologies help to find remedies for strain or injuries.

Median nerve reached to the hand through wrist and gets compressed. It is a very common disorder due to that pain in the carpal tunnel area. Symptoms of patients like physical examination, and electrophysiological testing are diagnosis methods after reporting by patient. Arthritis, genetic tendency etc. work-related factors are the other causes of CTS [1]. In daily

routine activities require repetitive and regular hand movement; that will increase the possibilities of CTS. CTS is not found in computer users only, also found in factory workers, musicians, carpenters, and typists because they are constantly performing repetitive hand movements with the same posture [2]

The excessive use of computing electronic devices and mobile phones are subject to repetitive movement of hand and wrist that will increase the rate of carpal tunnel Syndrome. Hand stretching exercises are also effective for carpal tunnel syndrome. Addition of a motion tracking system feedback system with exercises improves the exercise results. Task execution can be affected by Pain and distress in the hand and can cause loss of hand movement [3].

To design an efficient wearable electronic system on the body, following parameters must be considered for the accuracy and precision of the system. To design such a system the exact location to mount the sensor is an important task. To find the exact location of a sensor one must have knowledge about anatomical structure of joint and particular segment [4].

To manufacture ergonomic keyboards, Mice and wrist and palm support systems, various system designs were invented. Once CTS has been detected or symptoms are present then some non-surgical treatments are available like relaxing exercise and special training. When the pain becomes intolerable, surgery is the main treatment. The efficiency of surgical treatment depends on how long the patient had CTS [5]. To perform various tasks like grasp, grips, and rotation at each joint humans need 22 degrees of freedom which results in flexion / extension, adduction/abduction, and radial/ulnar deviations [6]. Some work patterns and hand movement like bending, gripping, holding, twisting, and typing may cause work-related musculoskeletal disorders (WMSDs).

CTS is a narrow pass way of ligament and bones at the joint of wrist and hand by which finger flexor tendons are allowed to translate during grasp. Median nerve passes through the same pass ways, this controls vibrations of the palm (Except of the little finger), as well as impulses to some small muscles in the hand that allow the fingers and thumb to move [7].

2. Background

Daily life of users has been affected by wearable devices. Technologies are affecting or involved in many aspects of our life; social networking communication and shopping on e-commerce websites [8]. Wearable technologies are used for detection of repetitive movement. Smart watches, hand gesture recognition and TOMO hoc are the wrist wear system examples which are currently used by the human. The aim is to provide a review of the studies based on hand wearable devices and expand the interface of commercial devices [9, 10].

3. Methods of Evaluation

3.1 Motion-Tracking and Monitoring Systems

Enforcement and supervision are some limitations for exercise-based intervention for CTS despite the benefits. Preventive exercises interventions are based on workplace scenarios [11]. These exercises are designed for employees without any supervision. Lack of motivation, awareness, time, and response are challenges for an employee to overcome before an exercise intervention. These challenges can be resolved through virtual interactive environments and games that are able to better stimulate and engage the user while providing them response dynamically [12].

A flex sensor based wearable monitoring device able to detect changes in the wrist position. This design uses analog to digital converter and transmits data to the computer for further processing and analysing. This system proposed minimal intrusion to patients and long-term mobile monitoring can be enabled by using non–invasive methods. Feedback system makes the device enable the user to alert the user for extreme conditions. To improve the diagnosis and treatment process of CTS, A system can be developed as an assistive and therapeutic wearable device. A flex sensor-based device was designed to record multiple sensors data wirelessly and collect data for evaluation [13].

To measure wrist and forearm angle measurement body mounted IMUs with gyroscope and accelerometer were used. This kind of system design gives sensor orientation space that can be

used to measure orientation of body segment and joint angle measurement. IMUs sensor-based system accuracy and correctness are good for human motion measurement [14]. Two IMU sensor-based systems have been designed which are enough to track the three degrees of freedom. The actual precision depends on the sensor quality and the sensor mounting on the body. IMU's, including accelerometers, gyroscopes and magnetic sensors are correct in orientation measurement without external cameras and actuators. These devices are easy to mount on textiles without impairing freedom. Data fusion algorithm was used to generate combined output of multiple sensors which further analysed excluding noise [15].

After collection of data from various microcontrollers, Data can be sent to a computer or laptop via serial communication for further analysis. Various tests like the Wilk test and T-test can be used to compare the difference between normal and extreme conditions. For statistical analysis SPSS software can be used. The aim of the experiment was to develop an economical wearable system to track joint angle using IMUs [16].

The widespread use of computer devices, video games and mobile phones are subject to tedious movements of hand and wrist which increase CTS inside users. There are various hand stretching exercises which are effective for carpal tunnel syndrome. If we add some motion tracking system with these exercises with a feedback system it improves the exercise results. This experiment was a system designed to promote these exercises. This system consists of a motion tracker including infra light emitters and cameras for depth detection. Leap motion sensors can track on .7mm with a tracking area of 609.6mm on each side. The GUI provides instructions similar to exercise guides [18].

3.2 Wearable Electronic Glove

The idea proposed in this article is totally different from recent research. It is totally based on inventing a glove which will give direction to work in the field of diagnosis of CTS. These gloves will provide some initial data regarding the pressure exerted on each finger while undergoing different tasks and this data will surely help to develop rehabilitation devices for wrist curing the problem of carpal tunnel syndrome. The author saw the problems of wrist pain in the wrist with a different angle. Tedious Strain Injury term is like a sunshade that covers a cluster of disorders, which usually initiate and grow by monotonous movements and that movement is the cause of disorder in the muscles, tendons and nerves. It was found that a glove was developed to track fitness exercises by collecting the force values by using sensitive resistors during the practice by an athlete. This glove helped to diagnose and treat various hand-related problems [19].

Systems are proposed to develop an affordable wearable hand glove to detect and diagnose RSI. An electronic glove used Arduino based hardware and force resistive sensors, which converts the results into kilogram-force. This converted data can be displayed in a graphical form on a computer system. The applied force on any object can be measured and evaluated such as an exercise ball. The observation provides the possibility of diagnosis and treatment for individual fingers or associated tendons. In the experiment, the extreme pressure applied on the ball was recorded at intervals of 10 seconds and a maximum period of 120 seconds. Result is variation in exerted pressure on each finger is visualized over a personal computer. It is possible to understand that each finger applies an amount of Kgf for the same time interval [20].

This design has described an electronically controlled device, which records the force value and posture of the wrist during working with a computer. Sensors are used to record the force quantity applied by the fingers tip and various positions of the wrist. Software is also used with the hardware device to maintain record and process the data. Author observed finger movements and angle of wrist postures due to these repetitive actions, discomfort arises of muscles. On the basis of recent studies, the author found the reason behind the

instrument. Different occupations cause musculoskeletal disorders and one of those profession is frequent use of computers. Subsequently, with growing the time spent in front of the computer, WRUED is a common problem for computer professionals nowadays. Generally, computer operators are not aware about the right positions for hand movements and the force applied on the keyboard by the fingers tip [21].

Proposed electronic device used for recording fingertip force, typing speed, wrist posture and angle during work on computer. The movement that is recorded or investigated includes: extension and flexion of the wrist, radial deviation. The proposed instrument basically consisted of an electronic system that produced a voltage signal in reaction to the force exerted by the fingertips or wrist movements. These converted digital signals were provided to the computer for further processing and analysis. The data recorded by the software is used to present the result in graphical form [22].

3.3 Hand-Tool Designs

This study reported about the design, development and trial of a wearable system which can be tied on the body to measure angle between wrist-to-forearm for flexion/ extension during the work. System was developed by using microcontroller and inertial sensors, tested and compared by using two off-the-shelf screwdrivers operation, one long and one short in length. The extensive use of screwdriver tools in repetitive posture forms associated with user discomfort and had adverse effects on musculoskeletal health issues. This tool tested on 12 male participant's within-subject experiment and performed horizontal and vertical screw driver tasks. Upper extremities unfair posture, continued manual actions and forceful exertions creates discomfort, fatigue and trauma disorder. This happened due to excessive stress on soft tissues and compression of median nerve and blood vessels [23].

The proposed system made use of body-mounted IMUs. This system has the accelerometer and gyroscope to produce data by an estimation of the sensor orientation in space. Which can be used to study the angles between joints? Four trials were conducted by each participant. Results showed that long screwdrivers with narrow handles and short screwdrivers with wide handles caused significantly higher ulnar deviation of the wrist in both set-ups, while the short screwdriver promoted higher wrist extension in both set-ups respectively [24].

3.4 Hand rest and wrist support system

Hand related activities, such as bending, gripping, holding, twisting and typing are responsible for work related disorders. In ordinary life these movements are not harmful but some work patterns may act as a risk factor for work related musculoskeletal disorders.

Some studies are about the electromyogram for hand rest and wrist support while working on keyboard for long hours. Three prolonged typing prolonged was used for subjects for investigating the efficacy of two adopted strategies for reducing the trapezius, biceps brachii, and extensor digitorum communis fatigue. After one hour typing subjects induced muscular weakness and after 1-4 hours induced extensor digitorum communis weakness.

These tested occupational strategies were not effective for Trapezius muscle weakness. During the application of protocols rather than detecting fatigue for overall tendency, different behaviour patterns accessed for muscle exhibited. This was depending on the result of both preventive strategy applied and muscle mechanical role overall duration of the task. BB muscle fatigue was reduced by using wrist supports, during prolonged typing. The use of hand resting pauses reduced EDC fatigue in the duration of long typing. These results were found by the JASA analysis of EMG data. These two occupational studies had no effect on Tz muscle fatigue. The use of hand resting pauses and wrist support can be effective for the reduction of muscle fatigue and work-related muscle disorders. It was confirmed by the studies that this is effective for risk

for upper limb disorder in the duration of long typing [25].

4. Data collection and analysis

After collection of data from various microcontrollers, Data can be sent to a computer or laptop via serial communication for further analysis. Various tests like the Wilk test and the T-test can be castoff to compare the variance between normal and extreme conditions. For statistical analysis SPSS software can be used.

Weight of the carpal passage is recorded with the help of above explained techniques for assignment to process this information as examination purpose. Biosensor data collection procedure can gauge proper physical condition that can be changed over the succeeding yield tests into computerised numeric data. This data can be inspected with the help of a computer after giving parameters for investigation. After collecting information showing in an easy-to-use way is essential to handle so can implement Graphical User Interface [26].

After appropriate time of establishment of bio sensor on wrist it is detached from person. Sensor data is documented into the connected memory. Data can be analysed after getting it from memory in the following steps for further processing

1) Signal received from pressure transducer mounted on wrist is processed.
2) Sampled data send for Data acquisition.
3) Digital numeric data conversion
4) Numeric Data sent for processing (mobile application, computer etc).

Software available for data acquisition system interface or application based are used for biomedical diagnosis of carpal tunnel. Bio-signals from pressure sensors are recorded by device and sent for processing to the computer. Signals received from transducers go through noise removal and amplifier stage then send for data acquisition system for digital processing. Data acquisition unit converts processed data into digital to send to the processor [27].

5. Wearable Biosensors

To reduce the death rate and improvisation for the medical health care field new research and advances in the medical field are expanding as days go. Innovation is the new way to complete the task. Everyone should be disease free for the improvisation of the medical field practically that is not possible. So, we can avail better facilities for that only. Treatment can start for any disease at an early stage only when the presence in the human body is found. Diagnosis is the pre stage of cure of any disease. Sensors play a vital role for examining the human body with favourable electrolytes and biological variables. Sensors are the only device which provides physiological parameters of the human body in understandable format [28].

For medical field application used sensors are called biosensors. Biosensors have direct interaction with the human body. This study of bio-sensors comes in the field of biomedical engineering. With the help of biosensors, we can convert bio signals take out from the human body into electric signals. Biosensors have physical transducers for the conversion of physiological parameters into computer understandable format. Electrolytes of the human body and physiology are sensed by the sensor's biological element. Transducers convert physical parameters extracted from the human body into electric signals for manipulation [29].

Table 1: Sensor Technology Comparison.

Sensor Technology	Material	Related work	Advantages	Limitation
Flex Sensor	Carbon resistive elements Conductive ink and fiber optic technology	Cyber gloves which are used for gaming purpose	Bear higher Temperature range -35 to +80degree ease of placement	Decrease in accuracy overtime
Accelerometer based	Gyroscopes and magnetometers	Used in recognition	Less hardware required Higher data rate no need of A/D Converter Longer Life span	Tricky placement on the gloves Lot of noise in the reading
Vision based	Imaging cameras	Human computer interaction	Higher accuracy compares to sensor-based system	requires high performance computational resources
Hall-effect Sensor	Magnetic field	Robotics and health care	Low cost. Operating frequency is 100kHz.wider range of temperature. Long Life	Magnetic field interference
Stretch Sensor	Resistor and sensor deformation Fabric Constructed stretch. knit stretch	used in soft robots	Minimize the Error	Sensitivity depends on the size of the sensor so not constant. Slower response time. Lifetime limited
Magnetic Sensor	magnetic fields	used in aerospace, geology and medical science	variability in sizes	sensitivity changes with their size

6. Discussion

For further development of this system consultation of neurologists and doctors will be required. With the help of the trained specialist this system can be shaped with different methodology. Long term use of the sensor does not provide accurate enough data. Design of a system that monitors individual fingers is not possible because the human physiology system is interconnected. Experiment results depend on hand operating tool design, whether they are having long diameter or length and short diameter or length. Some systems need some improvement to detect ulnar/radial deviation.

7. Technical Challenges

For widespread use of hand wearable devices deployment some technical challenges need to be solved. Hand wearable electronic devices should be small and capable of storing large amounts of data. System should be secure and safe. Developed

systems should be secure and encrypted for the tracking

capabilities and must reduce privacy and security risk. The symptoms of disease may be different for individuals because of family medical history and genetics. Big data approaches can be misleading so hand wearable technology should be aware of small data collections. Alignment of devices also affects measurement quality and accuracy of collected data. Systems should be robust to detect accurate data when there is disorder between user and wearable.

We can make design capable of tolerating disorder with the help of computation approaches and using protocols like internal references or self-calibration. One consideration is having special importance in variations human physiology that the size or 3D conformation of different organs on which we are applying wearables. Wearables must be operated at different environment conditions like humid, wet and warm temperatures.

8. Future Aspects

A system can be designed for various wearable applications after some modification. Existing System can be improved for tracking fist motion and for implementing further exercises. Further studies possible for the use of motion tracker medical data for determinations with follow up valuation. The study gives a direction to work in the field of wearable biosensors for more improved well-being. It will provide new techno and create an idea to develop a device for regular monitoring of CTS in the human body. In which sensor and analyser processor will be embedded and that can be worn on the wrist for the regular monitoring of pressure variation in the media nerve. The device will repeatedly give an indication when there is a large expansion or swelling over the median nerve so that a human being can change the position of the wrist while undergoing his tasks. Also, the main future aspect of this study is that it will heat up the preparations for AI enabled bio sensors and medical devices to improve human health care. This study provides a base for electronics engineers as they can think about developing an IOT device for detection of CTS and proper treatment of it.

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 1990;112 (5): 317–319.
2. Chen X. Human motion analysis with wearable inertial sensors [dissertation]. Knoxville (TN): University of Tennessee, Knoxville; 2013.
3. Wu G, van der Helm FCT, Veeger HEJD. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion part II: shoulder, elbow, wrist and hand. J Biomech 2004;38: 981–992.
4. 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 1997; 22(2): 200–210.
5. Bianca Callegari PT, PhD, Marilia Maniglia de Resende PT, Msc, Manoel da Silva Filho. PhD Hand rest and wrist support are effective in preventing fatigue during prolonged typing 2016; Journal of Hand Therapy xxx :1e9.
6. D. Macgregor, Nintendonitis? a case report of repetitive strain injury in a child as a result of playing computer games, Scottish Medical Journal 2000; 45(5): 150–150.
7. Carpal Tunnel Syndrome fact sheet Nat. Inst. Neurol. Disord. Stroke 2006.
8. Danielle Soares Figueiredo, Marcia Aparecida Ciol , Maria da Conceiç-ao dos Santos , Leticia de Araújo Silva , Joseph

Bruno Bidin Brooks , Roger Amorim Santos Diniz , Helga Tatiana Tucci .Comparison of the effect of nocturnal use of commercial versus custom-made wrist orthoses, in addition to gliding exercises, in the function and symptoms of carpal tunnel syndrome: A pilot randomized trial 2020;45: 102089.

9. Michael Mack, Cheol-Hong Min. Design of a Wearable Carpal Tunnel Syndrome Monitoring Device 2019; 978-1-7281-2788-0/19/$31.00 ©2019 IEEE.
10. Gilsa Aparecida de Lima Machado, Antonio Jose Balbin Villaverde. “Design of an electronic instrumentation for measuring repetitive hand movements during computer use to help prevent work related upper extremity disorder.International Journal of Industrial Ergonomics 2011;41 : 1e9.
11. Michail Karakikes & Dimitris Nathanael, Development and testing of a wearable wrist-to forearm posture measurement system for hand tool design evaluation.
12. G. Burdea, Virtual rehabilitation-benefits and challenges, in 1st International Workshop on Virtual Reality Rehabilitation (Mental Health, Neurological, Physical, Vocational) VRMHR 2002 :1–11.
13. Anik, KMR & Oyon, Mahmudul& Hossain, Jonayet& Azad, AKM &Alam, Marzia. Data Processing Through Biosensors and Development of Simulation Software in Windows & Rt-Linux. 2012.
14. Alvaro Uribe-Quevedo, Saskia Ortiz, David Rojas, And Bill Kapralos, Hand Tracking as A Tool to Quantify Carpal Tunnel Syndrome Prevention Exercises 2016:
15. Andrew Heuser, Hristian Kourtev, Scott Winter, Member, Telerehabilitation using the Rutgers Master Ii Glove Following Carpal Tunnel Release Surgery: Proof-Of-Concept, IEEE Transactions on Neural Systems and Rehabilitation Engineering 2007; Vol. 15(1).
16. G. Garcia, V. Ramirez, O. Ramirez, J. L. Rueda, And C. R. Torres, Simplified Design of A Device For Wrist Rehabilitation 2019; New Trends In Medical And Service Robotics, MMS 65: 35–42.
17. Joo Chuan Yeo, Cassidy Lee, Zhiping Wang, Chwee Teck Lim,Tactile Sensorized Glove For Force And Motion Sensing.
18. Calina Sînziana Silişteanu, Daniela Maria Crăciun, Marius David,” The Importance of the Sensor Devices in the Recovery of the Patients with the Carpal Tunnel Syndrome,” 2016 International Conference and Exposition on Electrical and Power Engineering (EPE 2016), 20-22.
19. Wesley B. Silva1, Paulo F. S. Junior, Ewaldo E. C. Santana, Raimundo C. S. Freire,” Wearable Electronic Glove for Supporting the Diagnosis of Repetitive Strain Injury,” https://dx.doi.org/10.22161/ijaers.73.20.
20. Adnan Rashid, Osman Hasan,” Wearable technologies for hand joints monitoring for rehabilitation: A Survey,” Microelectronics Journal 88 (2019) 173–183.
21. Michael Mack, Cheol-Hong Min,” Design of a Wearable Carpal Tunnel Syndrome Monitoring Device,” 978-1-7281-2788-0/19/$31.00 ©2019 IEEE.
22. Yoshii, Y., Tung, W., & Ishii, T. (2017). Strain and Morphological Changes of Median Nerve After Carpal Tunnel Release. Journal of Ultrasound in

Medicine, 36(6), 1153–1159. doi:10.7863/ultra.16.06070

23. Ponmozhi, J., Frias, C., Marques, T., &Frazão, O. (2012). Smart sensors/actuators for biomedical applications: Review. Measurement, 45(7), 1675–1688.doi:10.1016/j.measurement.2012.02.006
24. Davis, G. (1986). Advances in biomedical sensor technology: A review of the 1985 patent literature. Biosensors, 2(2), 101– 124. doi:10.1016/0265-928x(86)80013-x
25. Koydemir, H. C., &Ozcan, A. (2018). Wearable and Implantable Sensors for Biomedical Applications. Annual Review of Analytical Chemistry, 11(1), 127–146. doi:10.1146/annurev-anchem-061417-125956
26. Patent - Diagnostic Apparatus and Method For Evaluation Of Carpal tunnel Syndrome
27. Liao, Y.-Y., Lee, W.-N., Lee, M.-R., Chen, W.-S., Chiou, H.-J., Kuo, T.-T., &Yeh, C.-K. Carpal Tunnel Syndrome: US Strain Imaging for Diagnosis. Radiology 2015; 275(1):205–214. doi:10.1148/radiol.14140017.
28. Yoshii, Y., Ishii, T., Tanaka, T., Tung, W., & Sakai. Detecting Median Nerve Strain Changes with Cyclic Compression Apparatus: A Comparison of Carpal Tunnel Syndrome Patients and Healthy Controls. Ultrasound in Medicine & Biology 2015;41(3):669–674.
29. Kartmann, Sabrina & Koltay, Peter & Zengerle, Roland & Ernst, Andreas. Pressure Transducer for Medical Applications Employing Radial Expansion of a Low-cost Polymer Tube. Procedia Engineering 2015.
30. http://nptel.ac.in/courses/118106019/ 38 [x] Schuind. Canal pressures before, during, and after endoscopic release for idiopathic carpal tunnel syndrome. The Journal of Hand Surgery 2015; 27(6):1019–1025. doi:10.1053/jhsu.2002.36541
31. Liu, B.-S., Huang, K.-N., Chen, H.-J., & Yang. Ergonomic evaluation of new wrist rest on using computer mouse.2016 International Conference on Advanced Materials for Science and Engineering (ICAMSE) 2016. doi:10.1109/icamse.2016.7840230
32. Anik, KMR & Oyon, Mahmudul &Hossain, Jonayet & Azad, AKM & Alam, Marzia. DATA PROCESSING THROUGH BIOSENSORS AND DEVELOPMENT OF SIMULATION SOFTWARE IN WINDOWS & RT-LINUX 2012. 10.13140/2.1.1995.936