5-1-2016

COMPREHENSIVE PERFORMANCE EVALUATION OF A WIRELESS GRIP STRENGTH MEASUREMENT SYSTEM FOR TELEMEDICINE

Kaustubh Shinde

COMPREHENSIVE PERFORMANCE EVALUATION
OF A WIRELESS GRIP STRENGTH
MEASUREMENT SYSTEM
FOR TELEMEDICINE

by

KAUSTUBH SHINDE

Presented to the Faculty of the Honors College of

The University of Texas at Arlington in Partial Fulfillment

of the Requirements

for the Degree of

HONORS BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2016

ACKNOWLEDGMENTS

I would like to thank the Honors College at UTA for giving me an opportunity to do valuable engineering research on top of our regular curriculum. From completing the Honors Undergraduate Research Fellowship to presenting at the Honors Research Symposium, it has been a really helpful experience. The Honors Senior Project has been very useful to me and has helped me learn key electrical engineering concepts and the art of documenting research. I would also like to thank my faculty mentor, Dr. George V. Kondraske for helping me and guiding me though each step of this project. I have learnt a lot from just observing and following his work ethic. I would also like to thank my team members in the electrical engineering senior design project, Alex Tambert and Francisco Villagran, who have worked equally hard to get our senior design project, on which my Honors project is closely related, completed.

Finally, I would like to thank my family and friends who have stayed with me and believed in me throughout my college years.

May 06, 2016

ABSTRACT

COMPREHENSIVE PERFORMANCE EVALUATION

OF A WIRELESS GRIP STRENGTH

MEASUREMENT SYSTEM

FOR TELEMEDICINE

Kaustubh Shinde, B.S. Electrical Engineering

The University of Texas at Arlington, 2016

Faculty Mentor: George V. Kondraske

Many daily functions require involvement of the flexor musculature of the forearms and hands; i.e., the muscles that produce grip strength. Grip strength is commonly used as a measure to track general wellness, disease progression, and the effects of therapeutic interventions. Most dynamometers simply show grip force generated on a display and lack data capture ability. As part of a more comprehensive, self-administered, web-based human performance measurement capability, a grip strength module is being developed and was the focus of a spring 2016 electrical engineering senior design project.

This project focuses on the performance evaluation of that system, which incorporates a self-contained handheld grip force sensor device interfaced wirelessly via

Bluetooth to a local PC. The PC serves as a web-based client to a remote server, containing a database to store results. A thorough performance evaluation of the system was designed and partially executed. Portions of the evaluation remain in progress. When fully developed, the system is intended to allow users to self-administered tests at home periodically, have results stored in a central database, and have a remotely located clinician review results as required.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure | Page

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Importance of Grip Strength

Grip strength is an important quantitative value that can be used to evaluate an aspect of performance reflecting a person's overall fitness level [1, 4, 5, 6]. Much of the strength involved is attributed to the forearm muscles that are highly involved in a gripping motion. By measuring and knowing one's grip strength, a person can compare their result to a recommended value, as well as see their progress over time.

Many doctors use different measures of muscular strength to test the health of a patient. Low grip strength can be an indicator that a patient is in poor health. Low strength is also related to a higher mortality rate, as people with lower grip strength tend to have other weak muscles, often including the heart [1].

Figure 1.1: Traditional Hand Grip Strength Improvement Exerciser [2]

1.2 Current Project

A web-based grip strength measurement and logging system, the University of Texas at Arlington (UTA) Human Performance Institute (HPI) Wireless Grip Strength Measurement System, was developed as a part of an EE Senior Design Project carried out during the spring 2016 semester [16]. This system consists of a grip force sensor unit that contains all the electronics for the system. This module is able to communicate wirelessly with a web-application also developed as a part of the project. The web-application has the capability to send the strength data to a database located on a remote server. The final packaging of the product can be seen in Figure 1.2.

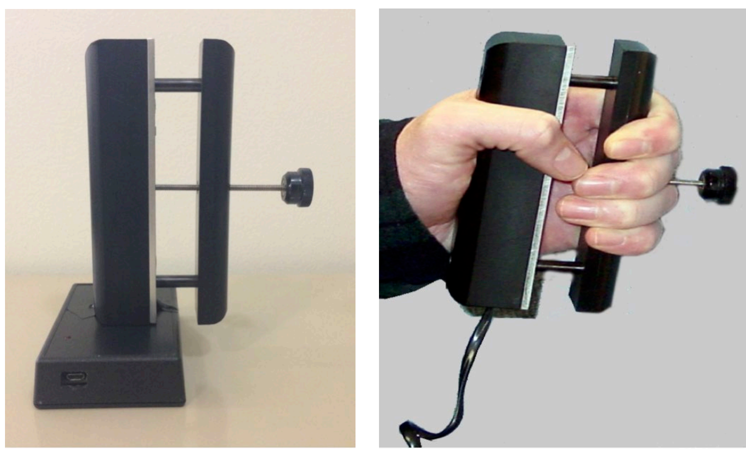

Figure 1.2: UTA HPI Wireless Grip Strength Measurement System (left) and an Example of Use showing the "Wired" Device (right).

The objectives of this present project are to perform comprehensive performance evaluation tests to determine measurement accuracy, repeatability, and differences between self-administered and supervised measurement results. The tests are divided into two types:

- Bench Tests: Determines the accuracy of the UTA Human Performance Institute Wireless Grip Strength Measurement System.

- Human Subject Tests: The focus is on validation of the self-administered aspect of the system and comparison to measurements administered by a trained examiner (i.e., supervised measurements).

Due to time limitations and complexities of human subject testing, it was only possible to plan and document that aspect of the evaluation prior to the submission of this report.

CHAPTER 2

LITERATURE REVIEW

Literature review was conducted regarding the relevance of grip strength and its measurement, different types of grip strength measurement devices, as well as telemedicine. With regard to the latter, the type of developing telemedicine contexts that motivated development of the UTA HPI Wireless Grip Strength Measurement System is briefly reviewed.

2.1 Importance of Grip Strength as a Biomarker

Grip strength provides a meaningful measure of a person's vitality. It is reflective of muscle mass and can be used to predict things like post-operative complications. By obtaining a reading of a person's grip strength level, health care practitioners can prescribe nutritional guidelines, exercises, and other interventions in an attempt to increase strength if necessary and improve the person's overall health and vitality [3]. The main consequence of the loss of muscle mass and muscle strength is limitations of physical performance and disability in older people. Studies show that low physical performance as a result of muscle mass and muscle strength is directly associated with low grip strength [4].

Grip strength is also a strong predictor of cardiovascular mortality and a moderately strong predictor of incident cardiovascular disease. As a study in *The Lancet* suggests [6], low grip strength is associated with higher case-fatality rates in people who develop cardiovascular or non-cardiovascular disease. These findings suggest that muscle strength can predict the risk of death in people who develop either cardiovascular or non-cardiovascular disease [5].

A study at Newcastle University, UK demonstrated that grip strength might act as a biomarker of ageing across the life course [6]. Loss of grip strength might be a particularly good marker of underlying ageing processes because of the rarity of muscle-specific diseases contributing to change in muscle function. [6] Along with playing a major role in strength development and tracking overall health, grip strength provides a key role in injury prevention. These and other type of use in which grip strength is essentially a biomarker are representative of those that fits well with telemedicine applications.

2.2 Telemedicine

Telemedicine is the use of telecommunication and information technologies to provide clinical health care at a distance. It helps eliminate distance barriers and can improve access to medical services that would often not be consistently available in distant communities [7]. While often broadly defined simply as the transfer of electronic medical data from one location to another, telemedicine really encompasses a broad range of emerging technologies, including telecommunications tools, information systems, and imaging technologies. Telemedicine is primarily intended to supplement the practice of conventional medicine and facilitate the exchange of information needed for diagnosis and treatment of illnesses [8].

Since the early 2000's, considerable research has been done in the area of telemedicine. One of the most popular books to be written about this topic is *Telemedicine: Medicine and Communication* [9]. This book tracks the surge in information technology and communications in the late 1990s and its impact on medicine. A journal article [10] describes one of the first uses of telemedicine when medical assistance was given to astronauts in the 1960s by NASA personnel at base stations on Earth.

In a research experiment at Göteborgs University in Sweden, a 3D-computer game was used as a training tool to promote motor relearning on a telemedicine platform on a subject in a laboratory setting. He was evaluated before and after treatment with a specific hand function task, a standardized grip force measure test and an upper extremity task. The telemedicine platform allowed professionals to record and evaluate the performance of the subject [11].

Telemedicine, and specifically the web-based attribute, is an integral part of the current project as this makes the current approach to grip strength measurement system unique.

2.2.1 Web-based Human Performance Measurement

A growing aspect of telemedicine is web-based human performance measurement. In general, this involves various self-administered internet-based tests to measure and track specific aspects of human performance. An example of this is the RC21x system (http://www.rc21x.com) that includes 15 brain performance capacity measurement tests [12]. All of these tests require only a typical laptop or desktop computer set-up to make these measurements. However, there is clearly a need to measure aspects of performance such as grip strength as part of such web-based systems. That type of measurement capability requires special hardware and software that fits into the general scheme of these types of self-administered test batteries. This has motivated the development of the UTA HPI Wireless Grip Strength Measurement Device that was the focus of the electrical engineering senior design project mentioned previously and the present evaluation project.

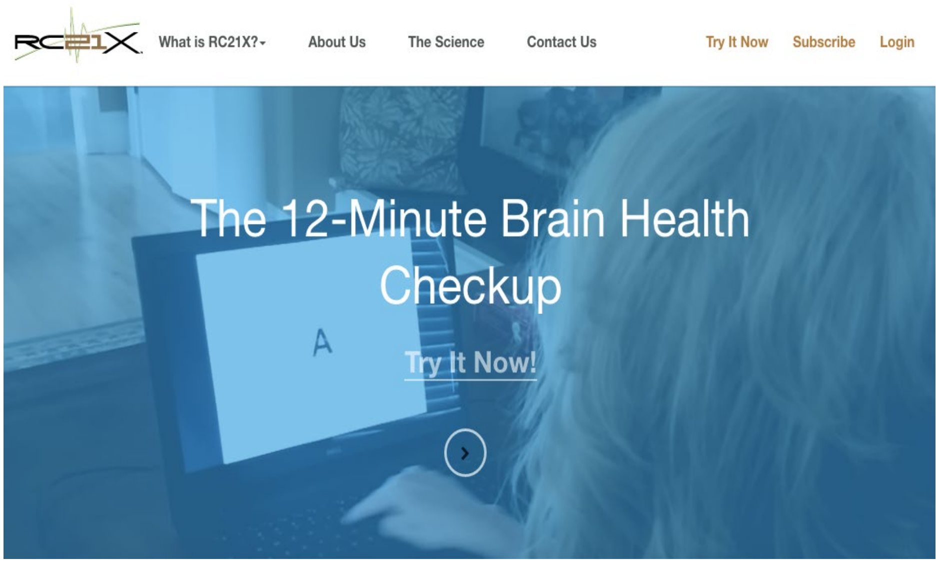

Figure 2.1: Web Screen Capture from RC21x [12]

2.3 Grip Strength Measurement Devices

The instrument used to measure grip strength is called a handgrip dynamometer. There are a number of examples of dynamometers in the market. Many studies have been carried out related to grip strength measurement. Grip strength measurements of athletes in various sports have also been recorded and analyzed [13]. Factors affecting grip strength measures have been identified as well [14].

Most devices use a mechanical gauge that the user must read out as they are squeezing the grip. This is less than ideal as there is no way of recording actual peak value, only what the user believes they have seen. Also, most of these devices have no way of recording past values in any way. It is left up to the user to record results, which can be cumbersome. While popular and widely used, the Jamar Handgrip Dynamometer, as seen in Figure 2.2 uses hydraulic pressure to move a mechanical gauge.

Figure 2.2: Jamar Handgrip Dynamometer [15]

Another device less commonly used, is the Camry Electronic Hand Dynamometer, shown in Figure 2.3. This design uses a digital display that is capable of reading a peak value. This device can keep track of results from recent tests, but only within the device itself.

Figure 2.3: Camry Electronic Hand Dynamometer [15]

Another type is the Multichannel Strength dynamometer, shown in Figure 2.4. This device allows for measurement of strengths other than just grip strength. This also requires a direct wired connection to the computer.

Figure 2.4**:** Multichannel Strength Dynamometer [15]

A different kind of system that has recently been in development is the UTA HPI Wireless Grip Strength Measurement System identified in Chapter 1 [16]. A key aspect of this device has over other designs is that the user will be able to use the device at home, record the results, and have a remotely located clinician review the data all without leaving their house, having to schedule an appointment, and pay medical fees.

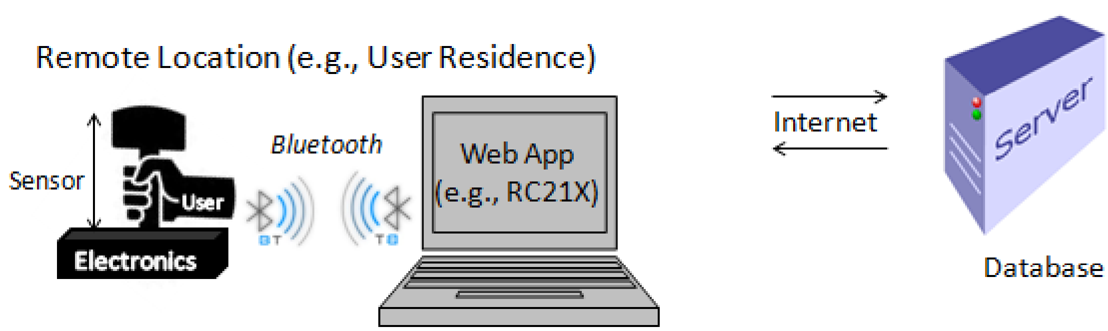

Figure 2.5: Components of the UTA HPI Web-Based Grip Strength Measurement System

This system consists of 3 parts; the wireless grip strength sensor unit, a local host computer running a web-based application, and a centrally located server. Data logging and handling are done in a web-based application that acquires the grip strength data from the user and stores it in a database server using a MySQL format. The local host computer is connected to the main server by the application running on the local PC.

CHAPTER 3

METHODOLOGY

The performance evaluation comprises of two types of tests: bench test and human subject tests. Prior to describing methods for each, a general overview of the web-based grip strength measurement system operation is provided.

3.1 General Overview of System Operation

To access the system, the user first pairs the Bluetooth module with their computer. This is a one-time event; it does not have to be repeated on subsequent sessions.

Assuming that pairing has occurred, the user employs their web browser to access the URL of the web application. Presently, an experimental URL is used.. A page is displayed with brief instructions and the user logs in, then a grip strength test is executed. The screen instructs the user to squeeze the grip strength sensor “as hard as possible” for 4 seconds, after a start “beep” occurs. After clicking a START button, the “beep” sound is generated. After the first “beep” sound, the maximum grip force value obtained during a 4 second period after squeezing the grip strength sensor is detected and is recorded by the web application and stored in the database. A double beep (“beep beep”) indicates the end of the test. Figure 3.1 shows a representative plot of the grip force versus time and illustrates the way the algorithm is designed to work in order to capture a measure of grip strength.

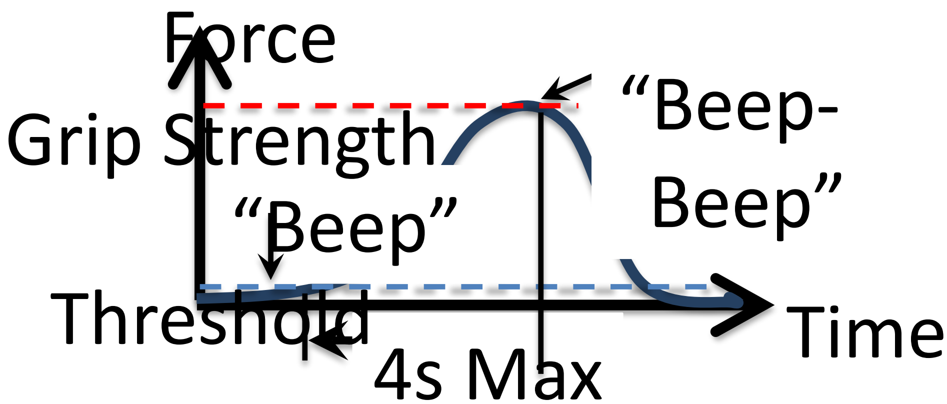

Figure 3.1: Force versus Time and Key Parameters Defining a Typical Grip Strength Trial

3.2 Bench Test

The overall web-based grip strength system consists of a chain of components linking the grip strength force from the basic force sensor to a server-side database. The software involved uses various data structures and calibration constants. To evaluate the basic integrity of these components, a bench test procedure was designed and performed. In this test, the force sensor was simulated to enable a focus on all other system components (digitization, wireless communication, etc.).

Normally, the force sensor produces analog voltages ranging from zero to 3.3V proportional to force. The static sensitivity of the force sensor unit incorporated into the design of the prototype system is 1V/151.51N. Voltages ranging from 0-3.3v with 0.3v increments were applied to the analog input of the microcontroller of the wireless grip force sensor unit. Voltage was obtained from a laboratory power supply (RIGOL Model DP832) that had a digital display of the output voltage. This voltage input was digitized using the grip strength acquisition software and algorithm (see Figure 3.2) and then wirelessly transmitted to a local computer via Bluetooth and then to the central server via the internet.

Data analysis consisted of computation of error and generation of a force versus voltage scatter plot.

% Error is computed as follows: %Error = |(Expected Value – Actual Value)/Expected Value| x 100

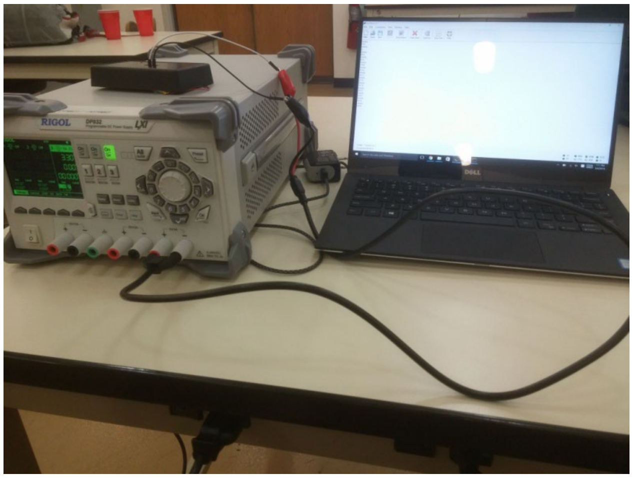

Figure 3.2: Bench Test Setup

3.3 Human Subject Tests

As noted previously, human subject testing was limited to only the planning of the required studies. Consequently, the description of methods that follow are in the future tense.

In this part of the evaluation, approximately 30 adult human subjects will be recruited from the UTA community to participate as volunteers. Approximately equal numbers of male and female subjects will be included, ranging in age from 18 to 70 years. The protocol will be submitted for review and approved by the UTA Institutional Review Board for human subjects' research.

Subjects will be tested in two situations: supervised and self-administered. A worst-case scenario will be used in which the self-administered trials will be performed first in order to eliminate learning that would result from supervised sessions.

The investigator will obtain informed consent from the subject. The subject will then be seated at a table with a personal computer and the wireless grip strength sensor unit. On-screen instructions will be provided addressing adjustment of the grip force sensor to the size of the subject's hand and describing proper execution of a grip strength measurement trial. The instructions will include a brief video that the subject can access and play as many times as they wish at any point during this self-administered session.

For the purpose of these studies, a "grip strength test" is defined as two trials, with a 10 second rest in between. The subject will be guided by printed instructions to: 1) use on-screen resources aimed at providing familiarization with the system and its components, 2) execute a practice test, and 3) use of the system to execute two grip strength tests that will provide the primary data used in analyses. Between each such test, there will be a minimum of a one minute rest. Thus, the sequence will be as follows:

1. Read familiarization instructions, watch video
2. Practice Test – Trial 1
3. Rest 10 seconds
4. Practice Test – Trial 2
5. Rest at least one minute
6. Test 1-Trial 1
7. Rest 10 seconds
8. Test 1-Trial 2

9. Rest at least one minute

10. Test 2 – Trial 1

11. Rest 10 seconds

12. Test 2 – Trial 2

Only one hand will be tested. This will be the subject's self-declared "preferred hand" (i.e., based on their stated handedness).

After the self-administered session is complete, the subject will be required to leave the lab room for at least 10 minutes and then return for the supervised session. The supervised session will follow the same sequence of steps listed above for the self-administered session. However, the subject will interact with the examiner and will not interact with the computer. The examiner will verbally provide essentially the same instructions as those provided as on-screen text or video. The subject will be free to ask questions and the examiner will be free to monitor subject compliance and provide corrective guidance when necessary. The examiner will also verbally coach the subject ("squeeze, squeeze, squeeze…") during the four-second test trial when force signals are being processed.

All strength measurement results will be stored in a database.

The primary aim of this study is to evaluate self-administered grip strength measurements relative to the more standard supervised administration. A secondary aim is to evaluate short-term test-retest reliability (repeatability) for self-administered and supervised situations and compare the two.

For evaluation of self-administered tests relative to supervised tests, the average of the two trials for Test 1 will computed to serve as the final measurement of grip strength for each subject under self-administered and supervised situations. Data analysis will consist of computing the mean of the absolute value of differences across all subjects, plotting self-administered versus supervised results and computing a Pearson correlation coefficient between supervised and self-administered grip strength measurements.

For the evaluation of test-retest reliability, the average of the two trials for Test 1 and the average of the two trials for Test 2 will be computed and plotted (i.e., Test 2 vs. Test 1) separately for self-administered and supervised sessions. Pearson correlation coefficients will again be computed, as will instraclass correlation coefficients, to serve as reliability measures. The difference in reliability for self-administered and supervised modes will be of interest.

CHAPTER 4

RESULTS & CONCLUSION

4.1 Bench Test Results

Table 4.1: Bench Test Data

Voltage	Expected Force(N)	Actual Force(N)	Error%
0	0	0.2	0
0.3	45.45454545	45.9	0.980
0.6	90.90909091	90.9	0.010
0.9	136.3636364	136.5	0.100
1.2	181.8181818	181.6	0.12
1.5	227.2727273	227.2	0.032
1.8	272.7272727	272.5	0.083
2.1	318.1818182	317.6	0.183
2.4	363.6363636	363.3	0.093
2.7	409.0909091	408.8	0.071
3	454.5454545	454.1	0.098
3.3	500	499.6	0.080

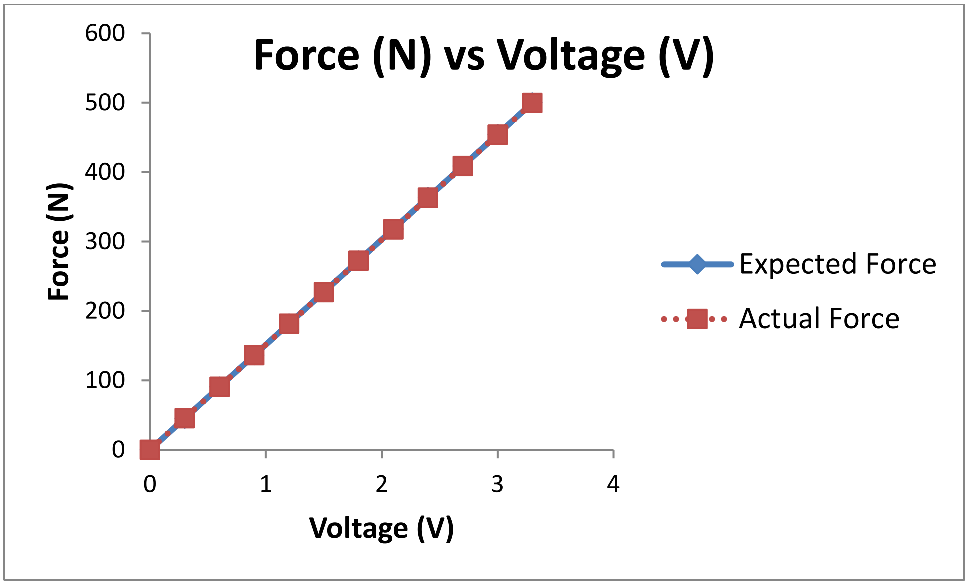

Figure 4.1: Graphical Display of Bench Test Results Exercising the System over the Full Measurement Range.

The equivalent force values obtained were within 0.183% of the expected values. Along with that, the actual equivalent sensitivity of our system (1v/151.39N) was very close to the expected sensitivity (1V/151.51N). The bench test validated the integrity of the web-based grip strength measurement system, indicating that the system is ready for human subject tests to proceed.

4.2 Human Subject Study Results

While the planned human subject study was not executed due to time constraints, examples of the type of results anticipated are provided here.

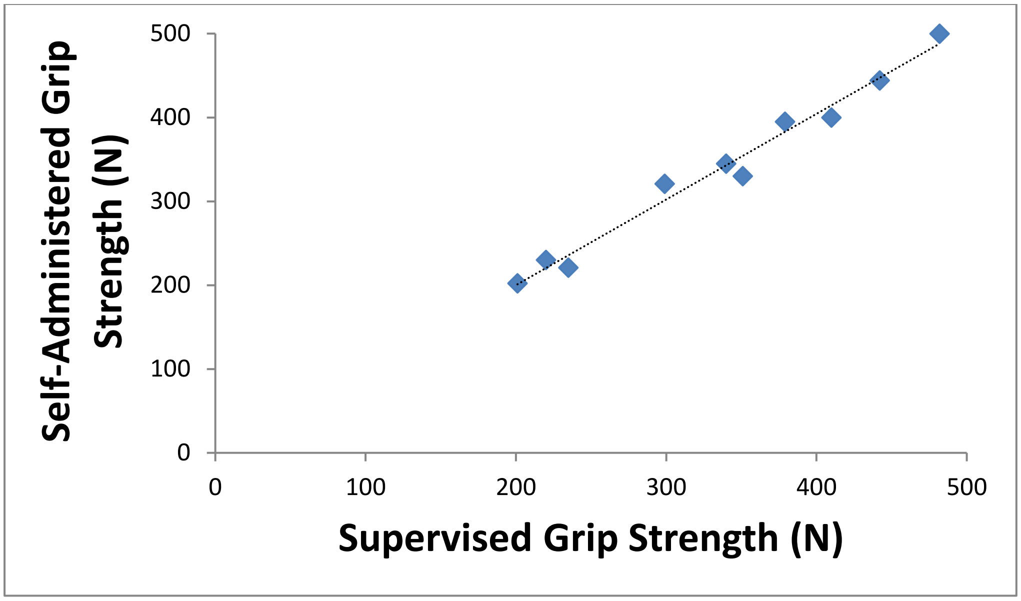

Figure 4.2: Comparison of Self-Administered to Supervised Grip Strength Measurements for 30 Healthy Adult Subjects (Hypothetical Data, for Illustration Purposes Only)

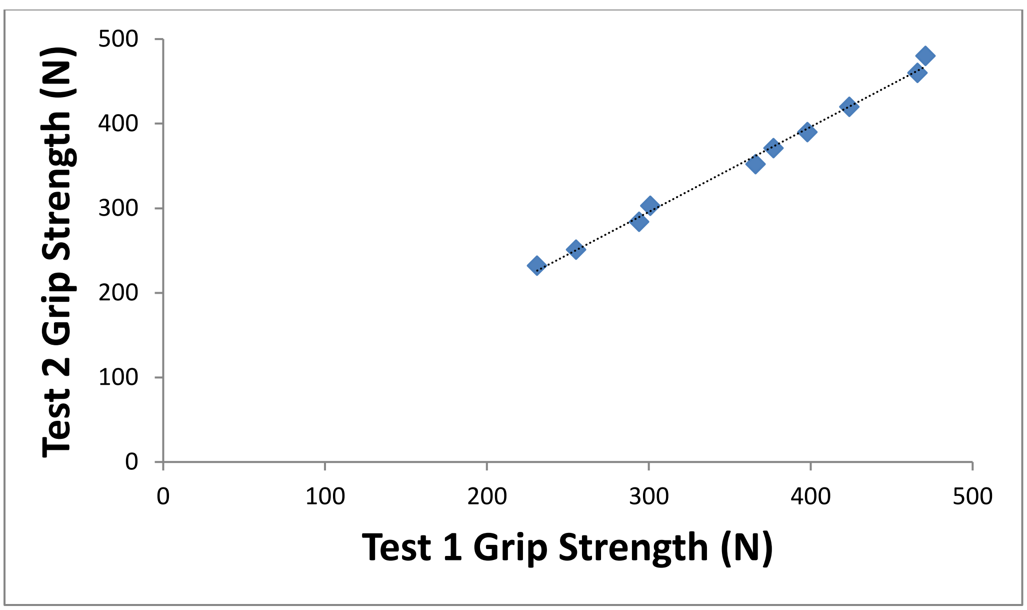

Figure 4.3: Test-Retest Repeatability for the Supervised Grip Strength Measurement Scenario for 30 Healthy Adult Subjects (Hypothetical Data, for Illustration Purposes Only)

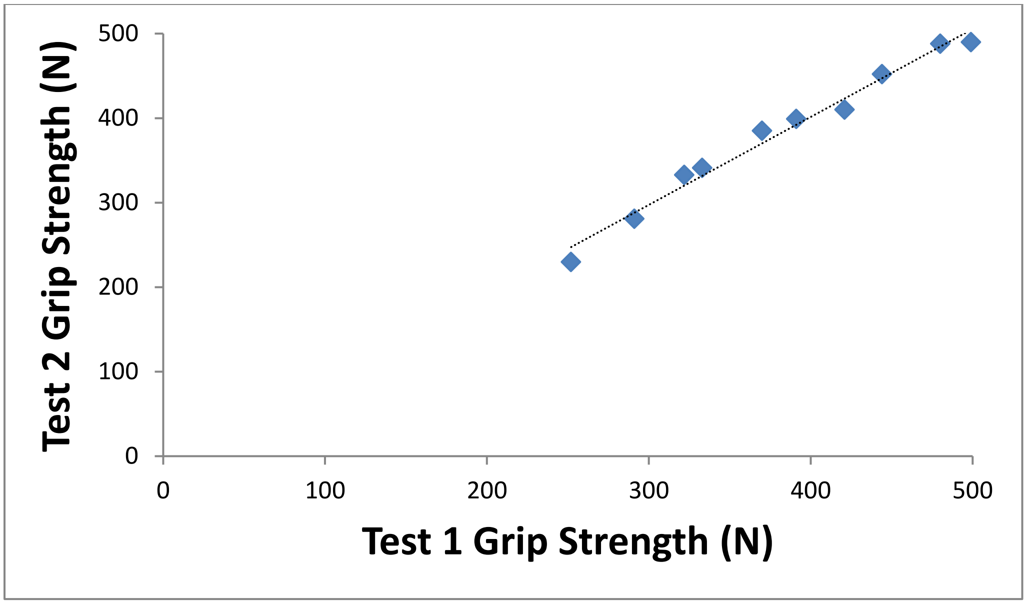

Figure 4.4: Test-Retest Repeatability for the Self-Administered Grip Strength Measurement Scenario for 30 Healthy Adult Subjects (Hypothetical Data, for Illustration Purposes Only)

4.3 Discussion and Conclusions

This research paper proposes a comprehensive performance evaluation of the UTA HPI Wireless Grip Strength Measurement System developed as a part of the Electrical Engineering Senior Design Project [16].

This system mainly consists of 3 parts; grip strength sensor, a microcontroller to wirelessly connect to a host computer and a web-based application. Data logging and handling is done in a web-based application, which inputs the grip strength data from the users and stores it in a database server, MySQL. The local host computer is connected to the main server by the application. A performance evaluation of this system is done to ensure that the product is reliable and convenient for the consumer to set up and use.

As a part of the evaluation, 2 tests, the bench test and the human subjects test, were thoroughly planned and partially executed. The bench test included testing the sensor with known references in the lab. This test was carried out using an industry-standard power supply powering the system, which was wirelessly transmitting data to a local computer via Bluetooth. The results from this test validated the accuracy of the system. Along with this, a set of human subject tests were carefully planned. These tests will be done with a group of subjects in a self-administered and supervised environment to ensure consistency and repeatability. The project is expected to be continued in the summer with the performance evaluation using human subjects planned out and expected to be done by the end of August.

REFERENCES

[1] Donnelly, L. (n.d.). Handshake strength 'could predict' heart attack risk. Retrieved May 07, 2016, from http://www.telegraph.co.uk/journalists/laura-donnelly/11603129/Handshake-strength-could-predict-heart-attack-risk.html

[2] How to Increase Grip Strength For Deadlifts | StrongLifts. (n.d.). Retrieved May 07, 2016, from http://stronglifts.com/deadlift/grip/

[3] Grip Strength Is Good Indicator of Overall Health - UConn Today. (2011). Retrieved May 08, 2016, from http://today.uconn.edu/2011/06/grip-strength-is-good-indicator-of-overall-health/

[4] Legrand, D., Adriaensen, W., Vaes, B., Matheï, C., Wallemacq, P., & Degryse, J. (2013). The relationship between grip strength and muscle mass (MM), inflammatory biomarkers and physical performance in community-dwelling very old persons. *Archives of Gerontology and Geriatrics, 57*(3), 345-351. doi:10.1016/j.archger.2013.06.003

[5] Leong, D. P., Teo, K. K., Rangarajan, S., Lopez-Jaramillo, P., Avezum, A., Orlandini, A., . . . Yusuf, S. (2015). Prognostic value of grip strength: Findings from the Prospective Urban Rural Epidemiology (PURE) study. *The Lancet, 386*(9990), 266-273. doi:10.1016/s0140-6736(14)62000-6

[6] Sayer, A. A., & Kirkwood, T. B. (2015). Grip strength and mortality: A biomarker of ageing? *The Lancet,386*(9990), 226-227. doi:10.1016/s0140-6736(14)62349-7

[7] What is Telemedicine? (n.d.). Retrieved May 07, 2016, from http://www.americantelemed.org/about-telemedicine/what-is-telemedicine#.Vy6SsfkrLIU

[8] Telemedicine. (2007). In *Encyclopedia of Emerging Industries* (5th ed.). Detroit: Gale. Retrieved from http://go.galegroup.com.ezproxy.uta.edu/ps/i.do?id=GALE%7CCX2869800128&sid=summon&v=2.1&u=txshracd2597&it=r&p=GVRL&sw=w&asid=9121e36613daec164c0869ab6ae288bf

[9] Buzug, T. M., Handels, H., & Holz, D. (2001). *Telemedicine: Medicine and Communication*. New York: Kluwer Academic/Plenum.

[10] Doarn, C. R. (2015). Development of Telemedicine and NASA's Contribution. *Aerospace Medicine and Human Performance, 86*(5), 504-505. doi:10.3357/amhp.4324.2015

[11] Peters, M. J., Nes, S. I., Vanhoutte, E. K., Bakkers, M., Doorn, P. A., Merkies, I. S., & Faber, C. G. (2011). Revised normative values for grip strength with the Jamar dynamometer. *Journal of the Peripheral Nervous System, 16*(1), 47-50. doi:10.1111/j.1529-8027.2011.00318.x

[12] RC21X - Main. (n.d.). Retrieved May 07, 2016, from http://www.rc21x.com/

[13] Borges Junior, N., Domenech, S., Dias, J., Silva, A., & Sagawa Junior, Y. (2009). Comparative study of maximum isometric grip strength in different sports. *Brazilian Journal of Kinanthropometry and Human Performance, 11*(3), 292-298. doi:http://dx.doi.org/10.5007/1980-0037.2009v11n3p292

[14] Maurissen, J. P., Marable, B. R., Andrus, A. K., & Stebbins, K. E. (2003). Factors affecting grip strength testing. *Neurotoxicology and Teratology, 25*(5), 543-553. doi:10.1016/s0892-0362(03)00073-4

[15] Handgrip Dynamometers. (n.d.). Retrieved May 07, 2016, from http://www.topendsports.com/testing/products/grip-dynamometer/

[16] Shinde, K., Tambert, A., & Villagran, F. (2016). *Wireless Grip Strength Measurement System for Telemedicine* (Unpublished Electrical Engineering Senior Design Project Report). The University of Texas at Arlington.

BIOGRAPHICAL INFORMATION

Kaustubh Shinde is an undergraduate senior electrical engineering student at the University of Texas at Arlington. His research interests are applied electromagnetics, antenna design, and MEMS. He has publications in IEEE-MDS and BMES conferences, and will be pursuing graduate school at UT Austin from Fall 2016.