Design of Hand Grip System with Focus on Tripod Grip Strength

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Abstract *— Tripod grip strength has been used as a key indicator of the overall state of strength and it is associated with mortality and disability. There are numerous ways grip strength can be measured. The measurement of grip strength in this project is using the power grip which is enclosing fingers around an object, bringing it toward the palm of the hand. This could be measured using a dynamometer. The objectives of this project can be summed up to design a device that will measure the grip strength of an individual and provide a graphical display that could be used by a physiotherapist to provide needed physiotherapy sessions to the patient. The device should also be able to track and detect the decrease in tripod grip over a period of several months. The data collected could be analyzed and represented in different forms to help users understand the results.*

Keywords — *Hand Grip System, Activities of Daily Living, Force Sensing Resistor*

I. INTRODUCTION

A. Project Background

The hand acts as the interface for humans to interact with, learn or identify the surrounding environment and extract a wealth of information. It plays a vital role in enabling human's growth in a mental capacity. Hand grip helps accomplish numerous tasks, ranging from high complexity to the simplest. The hand force applied by a pro basketball player has an impact on the game [1]. A task as simple as turning a door knob requires grip force [2] or even grip on weapons for protection of citizens or upholding law by police authorities [3]. Over the course of time as humans age there is a subsequent weakening of muscles [4] which is accounted as one of the symptoms of frailty including gradual decrease in body mass, endurance and physical activity. Physical frailty can be considered synonymous with disability and comorbidity [5]. Older people are prone to physical frailty with increasing age and lead to a high health risk in terms of mortality, falls and even hospitalization. Although the measurement of grip force may seem like a relatively simple task the reality is much more complex. The worth of data contained within the grip force is more than the displayed obvious. The value measured has been proven to predict future outcomes concerning an individual's health such as mortality, risk of disability and frailty [6]. As found in [7] Loss of grip strength can also be fatal with the risk of falls and accidents increasing.

B. Research Objective

This paper proposes a grip strength measuring system which would consist of a glove with pressure sensors to maintain the power grip. The data from the sensors would be used in monitoring and detecting decrease in grip strength through machine learning model to improve the hand grip for the elderly by early detection of reduced grip strength in the elderly so as to improve their quality of life.

II. LITERATURE REVIEW

A. Background Introducing Common Means to Measure Hand Grip Force

As discussed previously, hand grip strength can be useful to predict future outcomes and improve the quality of life for the elderly. There are numerous ways grip strength can be measured. The conventional method of measuring grip strength is through direct means using a hand dynamometer.

A dynamometer is a device that can measure power, torque or force applied on it. Several dynamometers are available today such as

Sphygmomanometer, JAMAR dynamometers, MIE digital grip, grippers [8] of which the JAMAR dynamometer is the most widely accepted. The JAMAR dynamometer is a sealed hydraulic system calibrated in kilograms or pounds. Although this design is the most prevalent today it has its limitations in that it fails to provide the best results in terms of accuracy due to its low sensitivity and inability to distinguish between maximal or sub maximal force applied [9].

Several other innovative methods have been proposed to measure grip apart from conventional dynamometers such as Novel's Monography, a sensor system that monitors grip strength and grip patterns [10].

B. Related Work

Although a wide range of studies agree upon the importance of hand grip strength the methods used to implement the device to measure the grip strength vary. A lot of information is included in the grip force of an individual. The review covers innovative methods designed to indirectly measure the grip force and some of several aspects to be considered in measurement of the hand grip such as the grip type, wrist position, placement of sensors, posture.

1) Grip Ball System: R. Jaber et. al and Chkeir et. al proposed a new method of measuring grip strength in [11] and [12]. This idea was conceived from the limitations of the dynamometer discussed previously and the advantages of an automatic system. The grip ball is an evolved dynamometer which measures the pressure applied on the ball. An electric circuit consisting of pressure and temperature sensors and ADC enveloped in a plastic ball.

Two of the main features of this device are its expandability for different hand sizes and adjusting its internal pressure through a valve connected to the airtight ball for inflation and its interoperability with other devices and its ability to adjust internal pressure in contrast to the hand dynamometer design. The soft and supple texture of the ball provides an added benefit of this design like the ease with which grip can be measured from an individual's hand bearing in mind that most people that would use a hand grip measuring device are often suffering from disabilities, such as Rheumatoid Arthritis (RA) or those well advanced in age. The sensors are controlled by an external controller, PIC 18LF13K22. The Power is supplied to the device using a rechargeable battery to maintain the intactness of the design.

Although both the papers proposed the use of the grip ball system, validity of this approach was tested using two different methods. In one approach, the pressure sensor used in the design was validated by comparing it against the hand dynamometer called the Martin Vigorimeter. In the other, validation was conducted using a hybrid device, using a combination of both the grip ball and the Martin Vigorimeter where the electronic components of the grip ball were replaced with the manometer of dynamometer. The paper [12] utilizes a hypothesis relationship established between the force applied and the pressure measured by grip ball using a quadratic regression equation $F = a P_A$, P_A being the pressure applied and a is the slope of the relationship. This model was evaluated against grip strength norms like Fried's criteria [13].

A system proposed by David J Hewson et al. called the Domo grip [14] uses the grip ball system along with other software interfaces to facilitate easy comprehension of data and measure grip in a remote setting without requiring professional assistance. A gap found in the paper was the position or posture of the arm during measurement.

The Grip Soft software would be used to measure the muscular capacity of the individual through a series of games and additionally be used for rehabilitation exercises. This data could also be monitored by healthcare professionals and used for future trials or research. The Grip Box would help in visualizing the data through the internet which records the force applied on the ball. The built-in memory would help retrieve previous results for comparison. D. Hewson et al also used this system to monitor physical frailty amongst other approaches for monitoring frailty [15].

2) Neuro Fuzzy Approach: Unlike the previous approach the distinctiveness of this approach one is not limited to measuring grip force but to also distinguish the grip force among pathological and normal persons [16].

To measure the grip the isometric force applied by the hand is translated to electrical signals using strain sensors. These signals are then amplified and preprocessed before passing them to a data acquisition system where the maximum, minimum and mean of the force signals are collected and stored. The data was classified using Adaptive Neuro fuzzy interference system (ANFIS), a fuzzy inference system where the membership functions are derived using a machine learning algorithm. The hybrid model featured in this article is an integration of fuzzy logic system (FLS) and artificial neural networks (ANN). The FLS is a system for rule-based decision making that uses its membership function for analyzing its input to determine an output whereas the ANN are algorithms that emulate the nervous systems of living beings.

The hardware design was based on the nutcracker model where two handles are joined together with a ring in between. The placement of the ring in the center was planned to improve detection. Up to four strain gages were placed on the ring. The strain measured from the deformation of the ring. This hardware information would be passed to the software design for data analysis. The data collected in the form of analog signals from the grip device was converted to digital using the data acquisition card (DAQ). This data is then filtered and averaged which contains the maximum and minimum signal frequency and is passed to the fuzzy module.

Although, the results show an accuracy of 90% certain drawbacks to this design prevail such as the imprecise number of fuzzy rules and functions to be used in the model is unknown, which would help reduce system error. This model was tested on a limited group of less than 500 individuals. The gap found in this article indicates that the feasibility and complexity of the system may increase and increase system error.

3) EMG signals: A very popular way of measuring grip force today is through EMG signals. These signals are passed to various machine learning models for improved accuracy. Electromyography can be defined as the study of the brain signals sent to the muscle tissue causing relaxation or contraction of movement. The measurement is recorded in electro grams [17]. These EMG signals can be measured in two ways. The first, invasively inserting electrodes into the muscles for measurement and the second, a non-invasive approach of measuring by placing sensors on the surface on the skin. The systems discussed here focus on the latter.

A relatively recent study by [18] explores the correlation between EMG signals and grip force. using the neuro fuzzy approach discussed previously in this review. The study proved that a strong correlation does exist between the EMG signals and force thereby concluding it as a valid method of measuring hand grip strength.

An interesting find by the Hongxin Cao et al. in [19] measured hand grip force using EMG signals to create a real-time myoelectric prostheses control system. The paper presented the proposition to testify to the extreme learning machine's (ELM) potential to predict handgrip force in real time. The research studies ELM's prediction accuracy of handgrip force from electromyography (EMG) signals.

C. Factors Impacting Grip Force Measurement

Several key factors play a vital role to enable the most accurate measurement of grip force such as the forearm and wrist position, elbow position, gender, age. Understanding the impact of these factors on Hand grip system (HGS). contributes to efficient and accurate results which would help determine the effective rehabilitation exercises and strategies to be adopted.

1) Elbow Position*:* J. Desrosiers et al in [24] sought to uncover the impact of elbow position in measuring HGS. The experiment was conducted on two elbow positions for elderly men, at 0° and 90° and measured using the JAMAR dynamometer. A total three measurements were taken with a rest period of 30s between each measurement and finally, the data was analyzed by considering the highest measurement among the three and the average of all three measurements using two-tailed paired tests. The results concluded that the elbow position had an impact only on the non-dominant hand by 5% and measured higher HGS when the elbow was flexed. The impact of this measurement may be a negligible percent depending on the accuracy required by a system as it would help minimize system error.

2) Hand Dominance: According to [25], agree with the generalized notion that grip strength is stronger in the dominant hand by at least 10%. This was found to be true for both genders at an age group ranging between 20 – 60 years. Two grip types were used in this paper for comparison, the power grip and pinch grip. The grip force measure by the dynamometer was analyzed using SPSS 8.0 Windows package program.

3) Wrist Position*:* The human arm works at many angles and therefore the data may vary according to the wrist angles producing biased results. Aiofe Finneran et al. and Danuta Roman-Liu et al. in [26] and [27] explore the impact of wrist position, grip type and posture in the precision of HGS measurement specifically for EMG signals. The study stated the effect of wrist positions on hand grip strength.

4) Forearm Position: L. G. Richards also pointed out in [28] that the consistency and accuracy with which the experiment conducted directly correlates to the collected data quality and so it becomes an important factor to consider in measuring grip strength. Different types of grip involve different sets of muscles.

The paper was focused on finding a correlation between the forearm position and grip strength measurement. The grip strength was measured among a certain number of people using the JAMAR dynamometer in three different positions- neutral, supinated and pronated.The paper also pointed out that the measurement varied depending on gender of the individual. The results deduced that the grip strength was significantly stronger in the supinated position in comparison to the other two and the weakest grip strength was found in the pronation position which in the cases of both genders. A gap found in this paper was the benefit of this approach over EMG.

The flexor muscles are located near the fingers and palm area and are also responsible for flexing of the wrist. The synergistic action of flexor and extensor muscles and the interplay of muscle groups is an important factor in the strength of resulting grip [30]. The Extensor muscles are located along the forearm [figure 1]

III. METHODOLOGY

The development of the methodology and design is carried out keeping in mind human-focused design principles and was approached from the perspective of a system designer which would mean that the system being developed would require continuous iterative testing and redefining. To help articulate

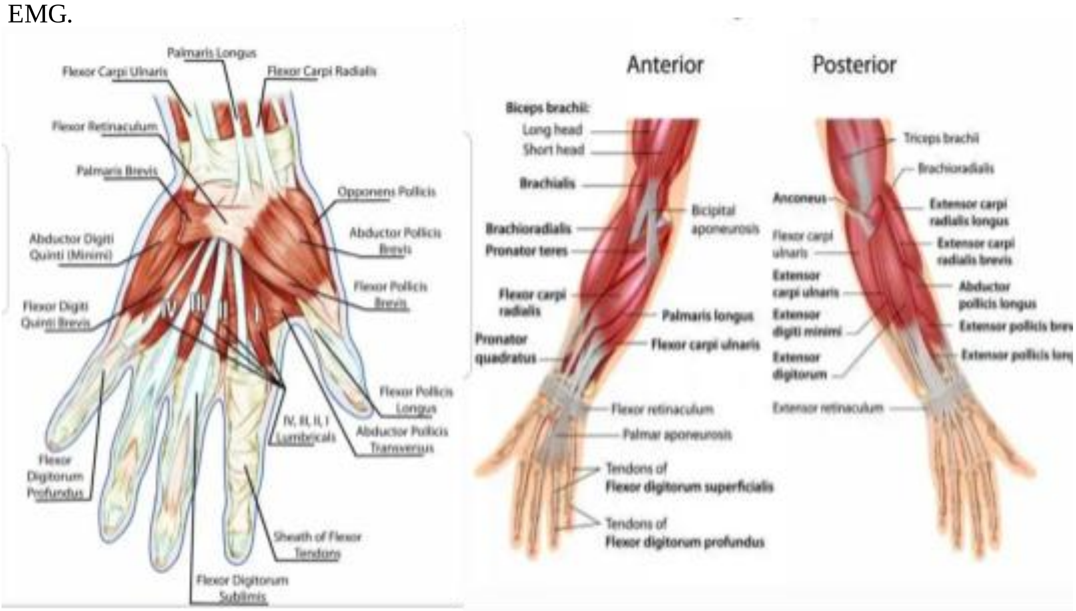


Figure 1: Thumb, Fingers and Forearm Muscles

Grip Type: There are multiple grip types involving the hand such as the pinch grip, hook grip, power grip. Of these grips the power grip proved to show maximum grip strength.

The power grip is the result of forceful flexion of all finger joints with the maximum voluntary force that the subject can exert under normal biokinetic conditions. The grip strength is affected from many conditions and some studies had been designed to identify these factors.[29]

Muscles impacting grip force measurement: The muscles that control the fingers lie in the forearm and hand. Two main categories of muscles are involved in hand grip – the Flexors and Extensors.

and provide a skeleton of the thought process behind the gradual development of the methodology the double diamond model [31] (See figure 2) has been adapted for this project.

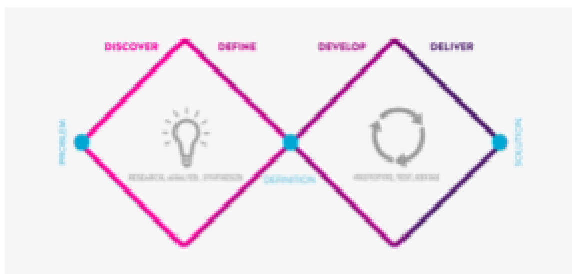


Figure 2: Double Diamond Model

This model has four distinct phases (discover, define, develop and deliver) where the development of the force measuring glove will be discussed in detail.

Phase 1 - Discovery: The discovery phase consists of drawing the parameters and boundaries of the project along with stating the goals or objectives to be achieved at the end of this process. The implementation of the design is carried out in two parts – hardware construction and software programming keeping in mind the fulfillment of the following objectives

- Measuring the total grip force using the pinch grip movement of all three fingers and recording data from sensors for subsequent analysis on the PC.
- Embedment of components on the hand glove
- Selection of components without compromising on the allotted budget as well as quality of product.
- Storing data on PC and plotting data using machine learning to predict loss of grip force.

Phase 2 - Define: This phase includes selection of main components. In this phase, the following were to be achieved:

- Selection and finalization of sensors keeping in mind comfort factor for elderly individuals.
- Glove type with standard hand size and durability to withstand soldering.
- Selection of conductive materials to and from the sensors to circuit
- Selection of components on the circuit

A. Sensor Selection

Criteria to be met upon finalization of sensor are as follows:

- Thin flexible sensors that are lightweight
- Easy attachment of sensors to hand glove
- Accuracy of the sensors
- Meet positioning requirements of the design in terms of width length

Based on the previously mentioned criteria, three sensors were identified [table 1] [32]. Out of the three sensors, FSR sensor was chosen as it met the above-mentioned factors.

B. Glove Type, Grip Type and Conductive Materials

The glove type chosen was verified to be flexible and comfortable and compatible with the standard size of the hand made of polyester material. The conductive material chosen for this project to establish a connection between the microcontroller was a conductive thread that is flexible and highly adaptable to sewing machines enabling strong connections and has the advantage of creating thin tracts on the inner and outer linings of the glove. Based on the literature review findings, the grip type employed for this design is the pinch grip. Using this grip (figure [3]) helps narrow down and focus on a specific function of the hand namely writing.

Figure 3: Dynamic Tripod

C. Circuitry and Circuit Component Selection

The circuit connection from the sensor to the PC including the microcontroller is shown in the schematic diagram and breadboard diagram in Figure[5]. The circuit consists of three FSR sensors

SENSORS	MATERIAL	ACCURACY	OUTPUT	PRICE	MANUFACTURER
Flexiforce 9811	Polyester sheet thin sensor	6.7 %	In volts	$55	Tekscan inc
Flexiforce A301	Polyester sheet thin sensor	10 %	In volts	$52.75	Tekscan inc
Quantum Tunneling Composite (QTC-SP 200-10)	Pressure sensitive sensor made of QTC	13%	Pressure	$47	Petrarch ltd

Table 1: Sensor Specifications

connected to give three distinct readings of the force applied by each of the three fingers (The thumb, index and middle finger). This sensor value is extracted using a voltage divider circuit along with a pull-down resistor creating a variable voltage as output. This output will be read by the ADC integrated in the Arduino UNO microcontroller.

Determining the required value of the pull-down resistor depends on the range of force expected to be applied on the glove. The output voltage of this circuit can be obtained using the following equation:

$$Vout = Vcc + \frac{R}{R + Rfsr}$$

where Vcc is the overall input voltage and R is the pull-down resistor.

Rearranging the equation, the sensor value is determined.

$$Rfsr = \frac{(Vout - Vcc)\,R}{Vout}$$

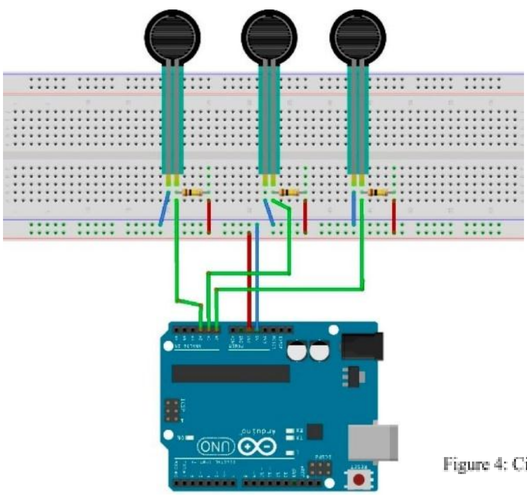
Phase 3: Develop: In this phase the sensors and circuitry placement on the glove were decided. The steps of development were as follows:

- Testing of finalized sensors and sensor placement at critical positions on the glove to measure the grip strength efficiently.
- Analyzing different circuitry options first on breadboard and finalizing final prototype on perfboard.
- Coding to extract from data from sensors
- Using data for further analysis and plotting of data

D. *Testing of the FSR sensor*

The FSR sensor was tested by attaching either ends to a multimeter and set to ohms as in figure [5].

Figure 5: Multimeter



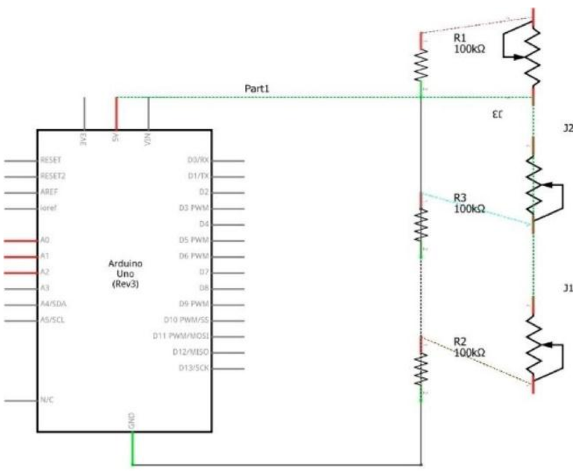


Figure 4: Circuit Board Schematic

E. Placement of FSR Sensor

In terms of sensor placement, a physiotherapist was consulted for further research in the following areas:

- The current trends used in Hospitals for measuring grip strength.
- The rehabilitation period for improved grip strength after a series of Physiotherapy sessions.
- The major muscles involved in HGS.

Figure 6: Sensor Placement

The sensors based on the physiotherapists advice and conclusion derived from the literature review, it can be concluded that the final positioning of the sensors should meet the two main requirements such as sensors must be situated on the glove fingertips and directly in contact with the load and must be placed in a manner so as to not cause discomfort or restriction of movement and as result would closely resemble figure [6].

F. Machine Learning Model

SVM or support vector machines is a machine learning algorithm which also happens to be one the most commonly used models for classification and regression analysis. SVM translates a data value in a dot and plots this on a n-dimensional space. The type of SVM used in this model is that of Logistic Regression or LR. LR works by dividing up data of two classes. This data is divided by using the kernel trick. In this project a pre-trained model is created of two classes, a group of individuals suffering with hand muscle issues and those that do not deal with them. A logical value is assigned to each class such as a 1 if the individual has hand muscle issues and 0 otherwise.

G. Overview of System Functionality

A force or pressure measuring sensor is placed at critical points on the hand glove, attached to the glove using an adhesive. The raw data is extracted

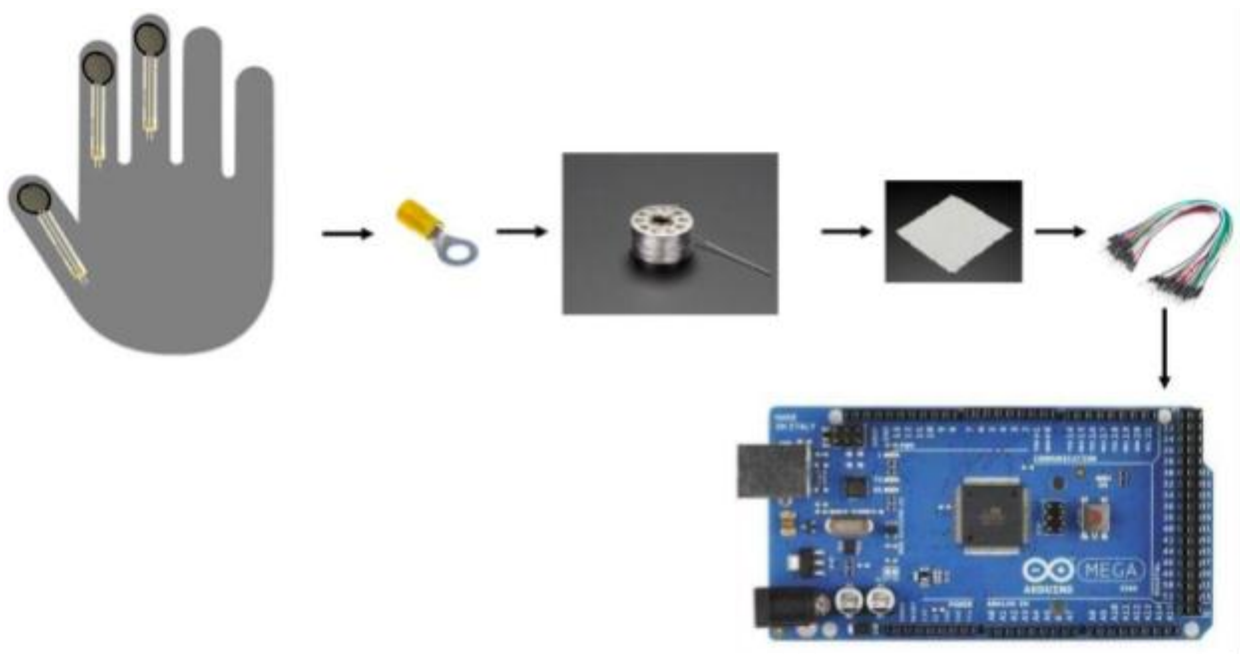


Figure 7: Overview of System

from these sensors using the Arduino microcontroller. This data is transferred to excel as a.csv file which will then be passed to the machine learning model data classifier support vector (SVM).

Once the data has been classified, the various module tools found in Python library such as Pandas Visualization built on Matplotlib. Seaborn, ggplot ,Plotly would be used to visualize the data and perform the comparison. See overview in figure [7].

F. Final Glove Arrangement

After selection and finalization of all the components, the arrangement was decided. In Figure [8]. To prevent cross-overs or short circuiting, the 5V tracks were connected on the outer side of the glove and the tracks through the conductive thread connected to the ground and resistors through the inner side of the glove.

IV. RESULTS AND ANALYSIS

Phase 4: Delivery Phase - Upon completion of the three previous phases, the final prototype design was implemented. See figure [9].

Figure 9: Prototype Design of Glove

After the hardware was set up, the final prototype design was tested on different volunteers. These volunteers upon wearing the glove performed the pinch grip and applied force to the load which is ideally a pencil or a rectangular object held by the pinch grip). With regard to the sensor operation, the data extracted from the sensors were plotted and displayed individually and the cumulative force was also graphed. Figure [10] displays individual data from each sensor. Moreover, the code was to display and determine whether force was actually being exerted by the individual or not ranging from no pressure, light squeeze, medium squeeze and hard squeeze figure. This data was recorded in real time and stored as .csv file.

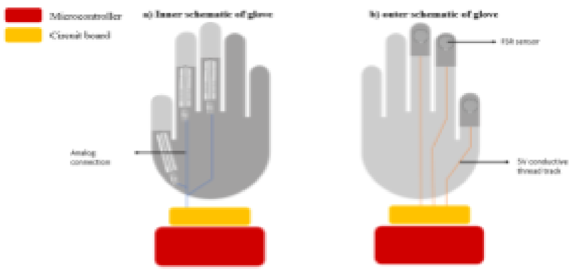


Figure 6: Glove Schematic Design

The sample data in the snapshot consists of an analog reading using the ADC (Analog to digital converter) of the Arduino Uno microcontroller. The set of 3 values correspond to each sensor on the hand. These values are then mapped from the analog range of 0 to 1023 to voltage range of 0 to 5V (in millivolts).

These voltage reading values are then converted

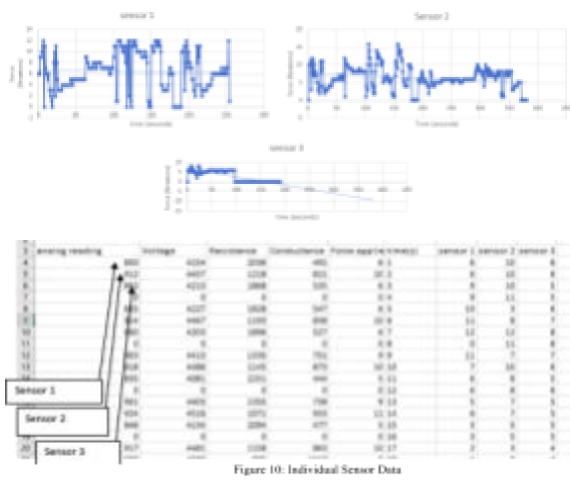


Figure 10: Individual Sensor Data

into force using Newtons. These force values are then organized into three separate columns of the individual sensor values.

In addition to the voltage and force values, the resistance and conductance is also obtained which helps to discern the increase of current in the circuit. This shows that as the resistance of the FSR decreases, the total resistance of the FSR and the pulldown resistor (10k resistor) decreases from about 100Kohm to 10Kohm. That means that the current flowing through both resistors *increases* which in turn causes the voltage across the fixed 10K resistor to increase. This can be seen in the sample data above. Further the net force from all three sensors were added to establish the total force.

Further research

For further research, we will use the machine learning model, Scikit-learn, a free machine learning library for Python. It features various algorithms like support vector machine, random forests, and k-neighbours. Dataset will be created after collecting data generated by the system when it is tested on various individuals. This dataset will be divided into 80% training and 20% test dataset.

In this research project the pre-trained dataset will consist of two classes. (figure 11)

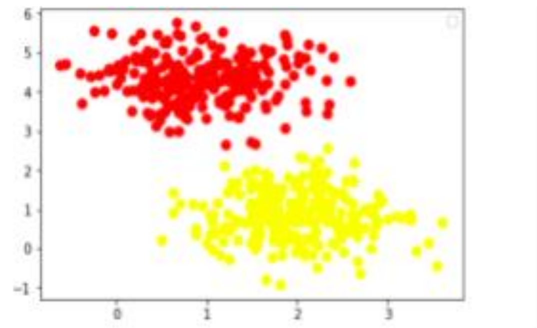


Figure 11: Data Classification

Class A: individuals with previous hand muscle issues

Class B: individuals with healthy hand muscles. The proposed SVM model will be used for classification[33][34].

V. CONCLUSION

Measurement of hand grip strength is not confined to knowing the muscle strength of an individual but also reveals other relevant information like the risk of disability, frailty and even in prediction of diseases. Several factors must be considered for accurate measurement of HGS like posture, elbow position, gender, wrist position and grip type.

This research is aimed to develop a system that is not limited to only measure grip force, like the standard use of dynamometers today, but also aims to visualize the data extracted from the device and draw a comparison between normative grip force and declining grip force.

The contributions of this research project is a complete system that is user friendly, portable and displays accurate data. The visualization is carried out by classifying the data extracted from sensors through a machine learning technique SVM. The has an added benefit of providing a report on the current condition of the pinch grip strength of an individual without the need of a specialist. Based on the research conducted thus far the systems designed in the past do overcome some of the limitations of the hand dynamometer but nothing further has been developed to implement a preventive measure through early detection. The data collected can be stored to compare improvement of grip strength in the future after therapy.

To better understand the implications of these results, future studies would include deploying the system at the hospital and collecting data over a long period (years) and implementing a machine learning model that would display and predict improvement of grip strength.

REFERENCES

[1] S. Priya, M. Rai and D. Joseph, "*Comparison between handgrip strength measurement of dominant hand and non dominant hand in basketball players*", Indian Journal of Physiotherapy and Occupational Therapy - An International Journal, vol. 12, no. 4, p. 126, 2018. Available: 10.5958/0973-5674.2018.00092.8.

[2] N. Gurari and A. Okamura, "*Human Performance in a Knob-Turning Task*", Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07), pp. 96-101, 2007. Available: 10.1109/whc.2007.71 [Accessed 8 May 2019].

[3] A. Copay and M. Charles, "*The influence of grip strength on handgun marksmanship in basic law enforcement training*", Policing: An International Journal of Police Strategies & Management, vol. 24, no. 1, pp. 32-39, 2001. Available: 10.1108/13639510110382241.

[4] B. Goodpaster et al., "*The Loss of Skeletal Muscle Strength, Mass, and Quality in Older Adults: The Health, Aging and Body Composition Study",* The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, vol. 61, no. 10, pp. 1059-1064, 2006. Available: 10.1093/gerona/61.10.1059 [Accessed 8 May 2019].

[5] R. Bohannon, *"Dynamometer Measurements of Hand-Grip Strength Predict Multiple Outcomes*", Perceptual and Motor Skills, vol. 93, no. 2, pp. 323-328, 2001. Available: 10.2466/pms.2001.93.2.323.

[6] J. Landsmeer, "*Power Grip and Precision Handling*", Annals of the Rheumatic Diseases, vol. 21, no. 2, pp. 164-170, 1962. Available: 10.1136/ard.21.2.164.

[7] J. Bear-Lehman et al., "*An Exploration of Hand Strength and Sensation in Community Elders*", Topics in Geriatric Rehabilitation, vol. 19, no. 2, pp. 127-136, 2003. Available: 10.1097/00013614-200304000-00006.

[8] G. Hamilton, C. McDonald and T. Chenier, "*Measurement of Grip Strength: Validity and Reliability of the Sphygmomanometer and Jamar Grip Dynamometer*", Journal of Orthopaedic & Sports Physical Therapy, vol. 16, no. 5, pp. 215-219, 1992. Available: 10.2519/jospt.1992.16.5.215.

[9] Jung-Hyun Lee, Young-Shin Lee, Sung-Ha Park, Moon-Cheol Park, Byung-Kun Yoo and Sung-Min In, "*A study on the human grip force distribution on the cylindrical handle by intelligent force glove(I-force glove)",* 2008 International Conference on Control, Automation and Systems, 2008. Available: 10.1109/iccas.2008.4694636

[10] "*manugraphy*", *Novel.de*, 2019. [Online]. Available: http://www.novel.de/novelcontent/manugraphy-product. [Accessed: 05- May- 2019].

[11] T. Rantanen, "*Midlife Hand Grip Strength as a Predictor of Old Age Disability*", JAMA, vol. 281, no. 6, p. 558, 1999. Available: 10.1001/jama.281.6.558.

[12] R. Jaber, D. Hewson and J. Duchêne, "*Design and validation of the Grip-ball for measurement of hand grip strength"*, Medical Engineering & Physics, vol. 34, no. 9, pp. 1356-1361, 2012. Available: 10.1016/j.medengphy.2012.07.001.

[13] K. Diokno et al., "*Delsys – Wearable Sensors for Movement Sciences"*, Delsys, 2019. [Online]. Available: https://www.delsys.com/home. [Accessed: 05- May-2019].

[14] A. Chkeir, R. Jaber, D. Hewson and J. Duchêne, "*Estimation of grip force using the Grip-ball dynamometer*", Medical Engineering & Physics, vol. 35, no. 11, pp. 1698-1702, 2013. Available: 10.1016/j.medengphy.2013.05.003.

[15] L. Fried et al., i"Frailty in Older Adults: Evidence for a Phenotype", The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, vol. 56, no. 3, pp. M146-M157, 2001. Available: 10.1093/gerona/56.3.m146 [Accessed 8 May 2019].

[16] D. Hewson, Ke Li, A. Frèrejean, J. Hogrel and J. Duchêne, "*Domo-Grip: functional evaluation and rehabilitation using grip force"*, 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology, 2010. Available: 10.1109/iembs.2010.5626395 [Accessed 8 May 2019].

[17] D. Hewson et al., *"Development of a monitoring system for physical frailty in independent elderly*", 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2013. Available: 10.1109/embc.2013.6610973

[18] W. Seng and M. Chitsaz, "*Handgrip Strength Evaluation Using Neuro Fuzzy Approach*", *Ejournal.um.edu.my*, 2019. [Online]. Available: https://ejournal.um.edu.my/index.php/MJCS/article/view/6412.

[19] M. Wininger, *"Pressure signature of forearm as predictor of grip force"*, The Journal of Rehabilitation Research and Development, vol. 45, no. 6, pp. 883-892, 2008. Available: 10.1682/jrrd.2007.11.0187.

[20] E. Yassine, B. Abdelaziz and B. Larbi, *"Implementation of adaptive neuro fuzzy inference system for study of EMG-force relationship"*, 2017 International Conference on Electrical and Information Technologies (ICEIT), 2017. Available: 10.1109/eitech.2017.8255292 [Accessed 8 May 2019].

[21] H. Cao, S. Sun and K. Zhang, "*Modified EMG-based handgrip force prediction using extreme learning machine*", *Soft Computing*, vol. 21, no. 2, pp. 491-500, 2015. Available: 10.1007/s00500-015-1800-8.

[22] G. Baudat and F. Anouar, "*Generalized Discriminant Analysis Using a Kernel Approach*", Neural Computation, vol. 12, no. 10, pp. 2385-2404, 2000. Available: 10.1162/089976600300014980.

[23] Hoozemans, Marco J. M., and Jaap H. van Dieën. 2005. "*Prediction of handgrip forces using surface EMG of forearm muscles*". Journal of Electromyography and Kinesiology 15 (4):358-366.

[24] E. Criswell and J. Cram, *Cram's introduction to surface electromyography*. Sudbury, MA: Jones and Bartlett, 2011.

[25] Y. Liu, H. Huang and C. Weng, "*Recognition of Electromyographic Signals Using Cascaded Kernel Learning Machine*", IEEE/ASME Transactions on Mechatronics, vol. 12, no. 3, pp. 253-264, 2007. Available: 10.1109/tmech.2007.897253.

[26] M. Wininger, *"Pressure signature of forearm as predictor of grip force"*, The Journal of Rehabilitation Research and Development, vol. 45, no. 6, pp. 883-892, 2008. Available: 10.1682/jrrd.2007.11.0187.

[27] J. Desrosiers, G. Bravo, R. Hébert and L. Mercier, "*Impact of Elbow Position on Grip Strength of Elderly Men*", *Journal of Hand Therapy*, vol. 8, no. 1, pp. 27-30, 1995. Available: 10.1016/s0894-1130(12)80153-0.

[28] N. Arinci Incel, E. Ceceli, P. Bakici Durukan, H. Rana Erdem and Y. ZR, "*Grip strength: effect of hand dominance."*, Singapore Medical Journal, vol. 43, no. 5, pp. 234-237, 2002.

[29] J. Desrosiers, G. Bravo, R. Hebert and E. Dutil, "*Normative Data for Grip Strength of Elderly Men and Women*", American Journal of Occupational Therapy, vol. 49, no. 7, pp. 637-644, 1995. Available: 10.5014/ajot.49.7.637.

[30] L. Richards, B. Olson and P. Palmiter-Thomas, "*How Forearm Position Affects Grip Strength*", American Journal of Occupational Therapy, vol. 50, no. 2, pp. 133-138, 1996. Available: 10.5014/ajot.50.2.133.

[31] "*What is the framework for innovation? Design Council's evolved Double Diamond*", Design Council, 2020. [Online]. Available: https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond.

[32] E. Komi, J. Roberts and S. Rothberg, "*Evaluation of thin, flexible sensors for time-resolved grip force measurement*", Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, vol. 221, no. 12, pp. 1687-1699, 2007. Available: 10.1243/09544062jmes700

[33] S.M. Biju, "*Analyzing the predictive capacity of various machine learning algorithms*", International Journal of Engineering & Technology, Vol 7, No 2.27, 2018 , DOI: 10.14419/ijet.v7i2.27.11013 Published on: 23-08-2018

[34] S.M. Biju, Mathew A. , ' *Comparative Analysis of Big Data Analytics Software in Assessing Sample Data* ' Journal of International Technology and Information Management: Vol. 26 : Iss. 2, 2017.