Monitoring Muscular Activity for Therapeutic Applications and Effectiveness to Encourage Patient Compliance

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Physical therapy helps many individuals recover some musculoskeletal function following trauma, disease, or age related impairments. However, physical therapy requires costs, travel, time, and compliance on the part of the patient to do the daily prescribed training exercises. These requirements limit accessibility and effectiveness of physical therapy. A system that could function at home, away from the clinic, instruct the patient, monitor their therapy activities, and report a summary of their performance would have the potential to improve accessibility, compliance, and effectiveness of physical therapy. Sensors such as electromyography (EMG) sensors, flex sensors, and accelerometers could potentially help to monitor the key activities related to physical therapy. The purpose of this project is to develop and test modules of an at home physical therapy system, focusing on monitoring the elbow.

Introduction

Millions of people face injury or impairment every year where physical therapy can improve the recovery. These injured individuals face many barriers to doing the physical therapy, and thus, possibly not achieving as full of a recovery as may have been possible [1]. These barriers include, cost, need to travel, and lack of compliance to do the prescribed exercises. Reasons for lack of compliance include forgetting details of the instructions, forgetting to do the therapy session, lack of confidence, and low enthusiasm. Studies have shown that by providing clear instructions that can be reviewed by the patient away from the prescribing physical therapist greatly improves the patient's compliance. Written instructions alone improved compliance by nearly 40% as opposed to only verbal instructions and demonstration [2].

Current models used for physical therapy include both routines that are completed with the therapist present, as well as routines that are completed at home. Both of these systems have different barriers that can prevent the patient from completing the exercises, however they both show similar efficacies in recovery [3]. There are products available that are aimed to help reduce barriers, however they are not targeted for physical therapy and are prohibitively priced. One of these products is the Athos (Mad Apparel Inc., Redwood City, CA) wearable technology for fitness, a compressive shirt and pant system with sensors used to monitor muscle activity for the purpose of determining muscle engagement. This is useful to some extent, however the target audience for this design is healthy individuals looking to improve their fitness. This type of technology shows promise in the field of recovery [4].

The purpose of this project is to develop and test a system that utilizes a sensor network to aid in monitoring the patient's elbow to determine if prescribed exercises are completed properly. This multi-sensor mapping technique has been proven effective in determining a subject's activities [5]. A microcontroller (MCU) will take in the signals from sensors in order to determine the type of exercises and number of repetitions. The analysis will try to characterize both form and range of motion. Sensors to be used in the system include an electromyography (EMG) sensor and an accelerometer. Outputs include a light emitting diode (LED), to inform the patient of a proper repetition, as well as data storage for external data analysis. Utilizing the EMG sensor and accelerometer will allow the monitoring of the patient's elbow movement in a three dimensional space. This data enables the MCU to decide if a repetition was completed. Once the decision was made of a successful repetition the LED will light up giving feedback to the patient. Completion of the prescribed repetitions will then allow the MCU to log the data to an external data source.

Housing the system will take the form of a wearable sleeve, a technique that has been shown to be effective [6]. The sleeve is able to position and house the sensors in a noninvasive fashion that is easy to use. This project aims to develop a noninvasive system that will be able to aid injured patients on their road to recovery, enabling more effective outpatient physical therapy by removing barriers to compliance and encourage exercise form and completion.

Design

An overall system block diagram was developed. The primary division is hardware and software subsystems. As seen in Figure 1, students took the basic linear regression the system would undergo.

When breaking down the system into the hardware design, the use of an EMG sensor was apparent to map the patient's exercises. For the EMG subsystem, signal processing was needed to handle the noisy signal produced by the EMG. To rectify the signal and notify the patient of a proper repetition the minimum hardware flow diagram was developed (Figure 2).

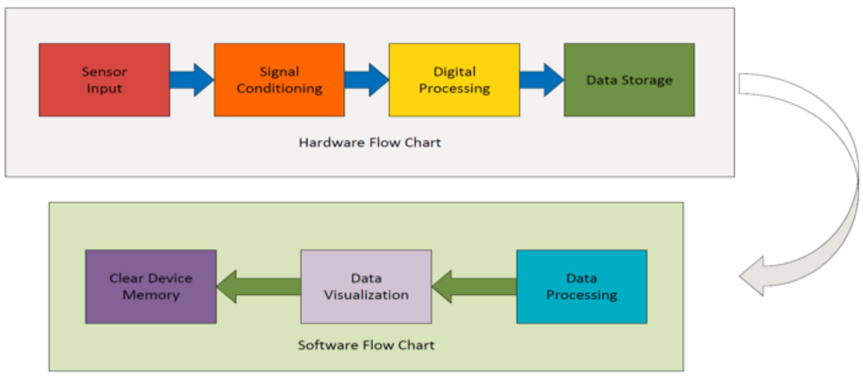

Figure 1. System block diagram

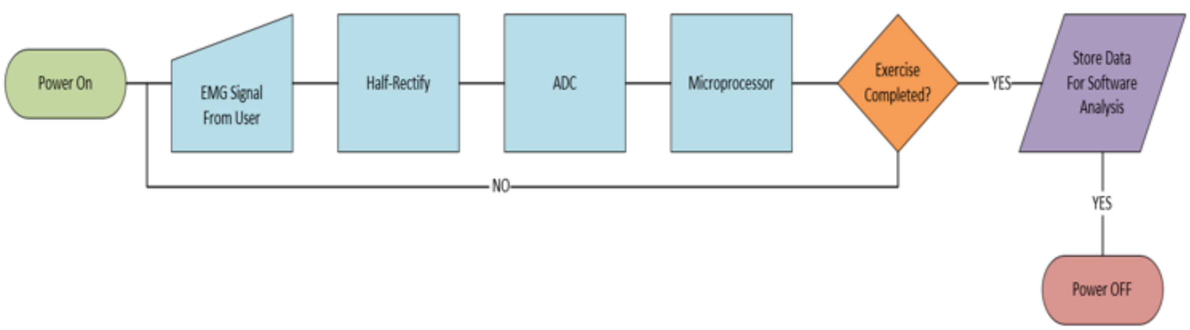

Figure 2. Hardware block diagram

As seen in Figure 2 the rectification of the signal takes an analog input from the sensor, half-wave rectify it, then converts it to a digital input for the microprocessor to manipulate it. It will continue to do this for the signal until the exercise is completed. Completing the cycle of signal processing the data needed to be saved to an external data storage for the computer program to analyze it.

As for the software for the microcontroller, knowing when a repetition was completed was the main focus. Utilizing the fact that an EMG and accelerometer could be used to find out muscle activation along with range of movement the code should follow a linear path to calculate a successful repetition.

Seen in Figure 3 the code shows how if thresholds are met from both the accelerometer and/or the EMG a repetition was successful. Also the code would send out a signal to a light emitting diode (LED) to notify the patient to then turn off after some sort of a delay. Finally when the repetition limit had been met the data would be written to the external source and ending the loop. With the data saved importing this to a computer program, the data will go through another set of analysis to visualize the data. Having the visualization allows both patient and therapist to read the data and segway into improving the routine.

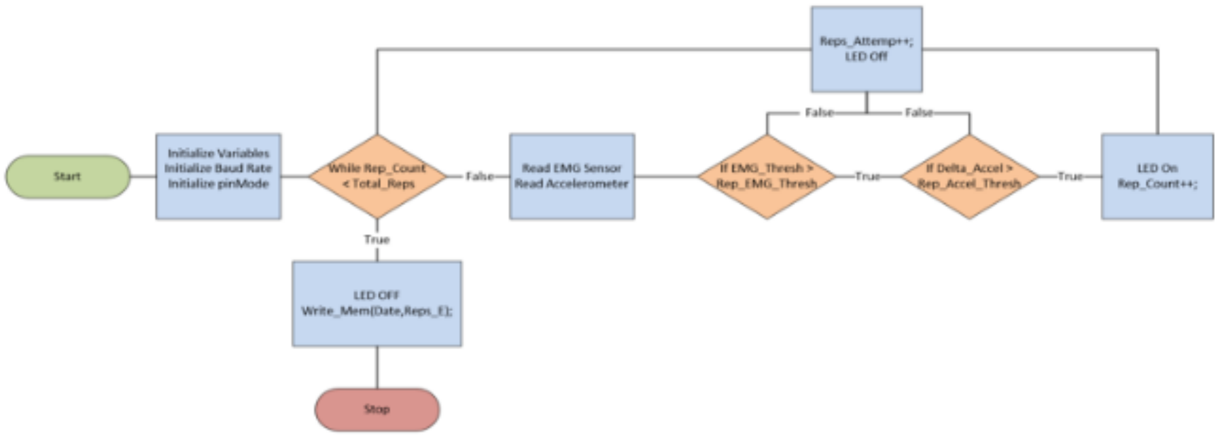

Figure 3. Software block diagram

Primary modules for the first prototype include an athletic compressive sleeve, an Arduino Uno, a self-rectifying EMG module, an accelerometer, and a secure digital (SD) card. With these components it has been possible to map the movement of the patient's forearm. The control module of the system will be centered around an ATMEGA326P microprocessor with an Arduino bootloader. The EMG module is able to detect contraction of the brachioradialis, a muscle in the forearm key for physical therapy exercises that this design focuses on. The accelerometer offers a different type of data collection that allows the mapping of movement beyond muscle activation. Placed at the patient’s wrist it is able to determine rotation and inclination, indicating the range of motion for the repetition. This combination of data allows the program developed to record the number of repetitions properly completed for each exercise.

The current prototype makes use of a pocket located at the top of the sleeve on the outer arm to house the arduino on the patient’s upper arm, a nonintrusive location. The pocket design allows the Arduino to be removed allowing ease of putting on or removal of the sleeve. Inside of the pocket is an SD card as well for the Arduino to write the data to. Opening in the sleeves have been made to allow the EMG sensor module, which is mounted to the sleeve, to be connected to the disposable electrodes placed to the patient's arm. The accelerometer, which does not need contact with the skin, is sewn onto the sleeve on top of the hand. This location allows for clearly measurable movement of the patient’s arm in three axis. With these sensors tests were performed in order to set thresholds that are used for logging completion of repetitions. As seen in Figure 4 the proposed design took on that particular form.

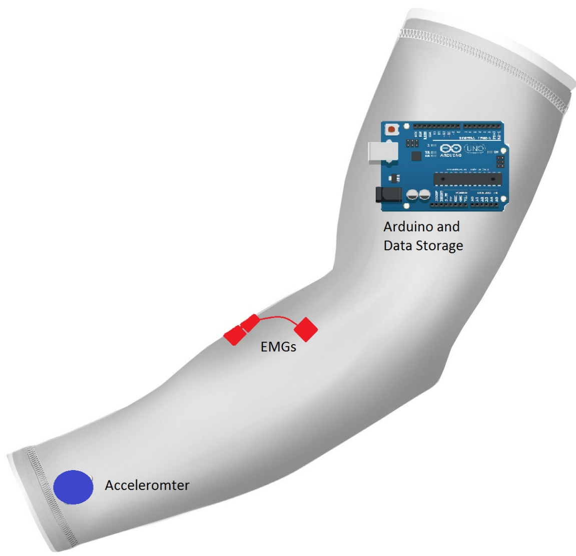

Figure 4. Conceptual sleeve design

Testing Methods

Preliminary testing gave way to a useful range of values that can be used in the program developed to recognize the patient's engagement of muscles and range of movement. The movements tested include rotating the wrist, pronation and supination, while held parallel to the ground from thumb-in to thumb-out, as well as the reverse, as data samples were collected. Another test collected data while the volunteers moved their wrist from maximum flex position (palm closest to forearm) to the maximum extend position (back of the hand closest to the forearm). During these tests, sensors were attached to the arms of the volunteers, and data was recorded while the exercise movements were performed. EMGs yielded values in the range of 7 to 435 for relaxed and fully flexed respectively. While these numbers are arbitrary they are useful in determining levels of engagement. A windowed average was used in order to make the data cleaner more manageable. With these values thresholds were set indicating the muscle has been relaxed at the lower threshold, and a fully engaged muscle at the higher threshold. The ability to determine the level of engagement for a muscle would allow tracking of the muscles activity. In the repetitive tasks performed in physical therapy, such monitoring of movements could be analyzed to characterize the success and compliance of the patient to do the prescribed exercises.

Testing for the accelerometer was done in a similar fashion in that data was collected from the volunteer's movements and analyzed to recognize the patterns in each direction that would be utilized in each exercise that this prototype is able to track. Along with the patterns that will be used to determine the patient's movement min and max values were also used in order to set reasonable thresholds for the tracking of completed repetitions. Together these sensors are table capable of registering when the patient has effectively engaged their brachioradialis while their arm in the proper orientation as well as determine that the forearm has moved to a satisfactory orientation for the desired exercise. When coupled with data generated from the EMG it is possible to determine if the patient has satisfied the conditions required for a specific exercise.

Results

Table 1: Raw data sample from accelerometer testing by rotating and lifting at the wrist

	Accelerometer					
	Thumb Out	Thumb Up	Thumb In	Wrist Up	Wrist Lev	Wrist Down
	2520	15740	7364	15104	2000	-11812
	2792	15816	6792	14752	1588	-14508
	2972	16024	7884	14980	1380	-15772
	3036	16044	8296	15088	1436	-15480
	2764	16076	8948	14856	1448	-15152
	2620	15988	8756	14696	1384	-15172
	2576	16064	6560	15228	1416	-14860
	2596	16040	6504	15068	1412	-15036
	2144	15832	6400	14680	1200	-15168
	2716	16064	6332	14244	1312	-15108
	2612	15980	6436	14680	1144	-15052
	2868	16052	6264	15092	1244	-15088
	2616	16100	6060	15060	1088	-15260
	2696	15948	6488	14780	1356	-15080
	2700	16012	6360	15100	828	-15032
	2736	15984	6460	14860	1428	-15152
	2656	15896	6668	14987	1396	-14508
Average:	2684	15980	6975	14897	1356	-14896
Min:	2144	15740	6060	14244	828	-15772
Max:	3036	16100	8948	15228	2000	-11812

Table 1 is a sample of data collected while the volunteer wore the prototype sleeve and performed the rotational exercises of pronation and supination. The results collected reflect the accelerometer readings while the arm rotated and held at the thumb out, thumb vertical, and thumb in positions. These unitless arbitrary numbers are useful in that they allow the MCU to log when the patient's arm has been successfully rotated in the y direction the desired amount. Table 1 reflects the same type of data collected for the movement of the wrist in the flexion and extension movements. This data is the change in the x-direction of the accelerometer.

Table 2: Raw data collected from EMG testing rotation of the wrist and squeezing a ball.

	EMG Sensor				
	Thumb Out	Thumb Up	Thumb In	Holding	Squeezing
	52	12	50	8	324
	75	11	28	8	255
	70	12	38	9	227
	79	14	29	12	305
	87	11	22	10	286
	96	13	23	9	427
	76	11	35	8	270
	54	19	38	10	278
	70	13	33	11	195
	61	13	36	13	435
	46	17	39	10	294
	56	15	30	8	310
	54	14	23	8	332
	49	11	27	8	242
	73	13	26	7	144
	58	12	17	8	190
	56	11	18	8	353
Average:	65	13	30	9	286
Min:	46	11	17	7	144
Max:	96	19	50	13	435

Table 2 contains a sample of data collected from the EMG using a windowed average, each data point representing 250ms of monitoring. The EMG collected data on the rotational movement while the volunteer held a hammer as a weight as the target exercise often prescribes. This test is able to reflect the different levels of engagement of the brachioradialis muscle used in flexing the forearm at the three positions observed previously. While the data collected is unitless it is used for comparison to previous values for the MCU to determine adequate engagement. The EMG was also used to collect data on squeezing. The low values were collected as the volunteer lightly held a foam ball while the high values were collected while the foam ball was squeezed tightly. This vast difference in the muscles engagement is clearly seen in the difference in magnitude of the collected data.

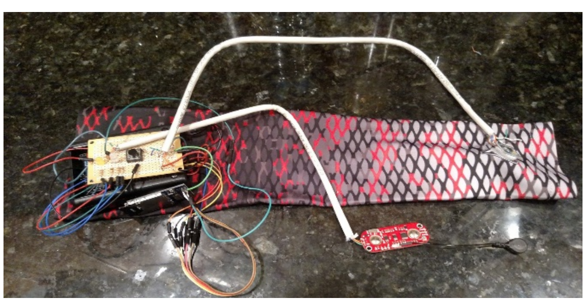

Figure 5. The prototype of the system with sensors, LEDs, SD card, and push button.

Figure 5 shows the prototype used for testing and data collection. While this prototype exemplifies the challenges experienced in the limited resources available for manufacturing, however this sample is able to read in, save, and visualize the data while being worn by the patient. A sample of the data visualization can be seen below in Figure 6.

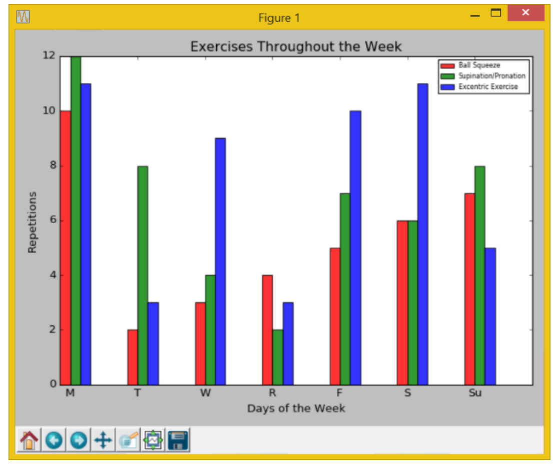

Figure 6. Example data output from the system.

In Figure 6 the data was visualized using Python 2.7.11 and the Matplotlib module. Shown on the bar graph are the three exercises and the number of repetitions completed per day of the week.

Conclusions and Future Direction

Early testing of the sensor module shows the design has promise for being suitable for monitoring motion related to the elbow, which could be analyzed for physical therapy for the recovery of an injured elbow. The multi sensor mapping system could be developed with these sensors to characterize a patient's movements could be developed with these sensors to characterize. This feedback should contribute to an increase the patient's confidence from home, reducing some of the barriers to compliance.

Future development for the project includes streamlining the design to a more aesthetically pleasing housing and less intrusive wiring runs. Besides improving the visual appeal of the device, a more stable housing will help in keeping wire connections secure. On board power will also be added in order to allow the system to be used with less tethering wires. Moreover, the algorithms for calibration and for characterization of the movements will need to be developed and tested.

References

1. Emmy M Sluijs, Gerjo J Kok, and Jouke van der Zee, "Correlates of Exercise Compliance in Physical Therapy", *PHYS THER* November 1993 73:771-782
2. Schneiders, A.g., M. Zusman, and K.p. Singer. "Exercise Therapy Compliance in Acute Low Back Pain Patients." *Manual Therapy* 3.3 (1998): 147-52. Web. 11 Feb. 2016
3. Ko, Victoria, Justine Naylor, Ian Harris, Jack Crosbie, Anthony Yeo, and Rajat Mittal. ,"One-to-One Therapy Is Not Superior to Group or Home-Based Therapy After Total Knee Arthroplasty." *The Journal of Bone and Joint Surgery (American*) J Bone Joint Surg Am95.21 (2013): 1942. Web.
4. Patel, Shyamal, Park, Hyung, Chan, Leighton, and Rodgers, Mary. "Journal of NeuroEngineering and Rehabilitation." *A Review of Wearable Sensors and Systems with Application in Rehabilitation*. N.p., n.d. Web. 11 Feb. 2016.
5. Taraldsen, Kristin, Torunn Askim, Olav Sletvold, Elin K. Einarsen, Karainnce G. Bjastad, Bent Indredavik, and Jorunn L. Helbostad. "Evaluation of a Body-Worn Sensor System to Measure Physical Activity in Older People With Impaired Function." *Journal of the American Physical Therapy Association*, 6 Jan. 2011. Web. 04 Feb. 2016.
6. Linz, Torsten, Lena Gourmelon, and Geert Langereis. "Contactless EMG Sensors Embroidered onto Textile." *Springer*. N.p., n.d. Web. 11 Feb. 2016.