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CHARACTERIZATION OF GRASP PERFORMANCE USING A SENSORIZED GLOVE SYSTEM

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ABSTRACT

We present a grasp performance evaluation system that uses a sensorized glove to measure the kinematics and the contact dynamics of human object manipulation. This system is envisioned as an alternative to visual evaluation methods currently used by skilled physicians to determine the severity of functional hand impairments due to blunt trauma (ligament injuries tin the fingers) and neurological disorders (cerebral palsy, stroke, etc.). The proposed grasp evaluation system can benefit physicians and prosthetists by providing an objective, consistent metric to evaluate hand function and potentially reducing the amount of time required for diagnoses. Human subject study involving grasps of daily objects were conducted to demonstrate the system's ability to accurately measure the kinematics and dynamics of grasping tasks, and generate graphical representations of the grasp contact dynamics with color map visualization.

Keywords: Grasp Characterization, Hand Impairment, Powered Prostheses, Postural Synergies

1. INTRODUCTION

Stroke is a major cause of motor and grasp impairments, and affects 795,000 people in the United States every year [7]. Within the affected population, 88% of patients experience hemiparesis, or partial paralysis, in the upper limb, leading to difficulty in grasping objects of daily living [1]. To diagnose stroke patients with hand impairments and develop effective treatment plans, physicians and therapists rely on visual indicators of grasp impairments, and/or use interactive grasp evaluations with questionnaires [2]. Although the interactive evaluation approach has proven effective in the diagnosis of impaired hand function, this approach requires inspection by trained professionals and is time consuming [6].

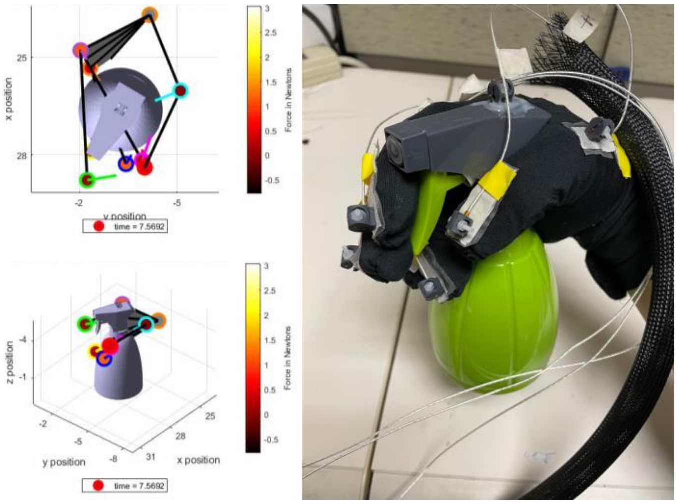

FIGURE 1: A FRAME OF THE GRASPING ANIMATION SHOWING THE HUMAN SUBJECT USING A SPRAY BOTTLE. COLORED CIRCLES REPRESENT FINGERTIP AND PALM SENSOR LOCATIONS, AND ARROWS SHOW THE RELATIVE NORMAL CONTACT FORCE VECTOR.

To streamline the evaluation of hand function, several researchers have explored the use of sensorized objects which measure the locations and magnitudes of forces applied to their surfaces during grasping and manipulation. [3, 4]. By monitoring the forces applied to daily living objects by healthy human subjects and comparing those to the forces generated by stroke patients, changes in motor capability can be quantified experimentally. Though this approach is promising, there are limits on how faithfully sensorized objects represent many of

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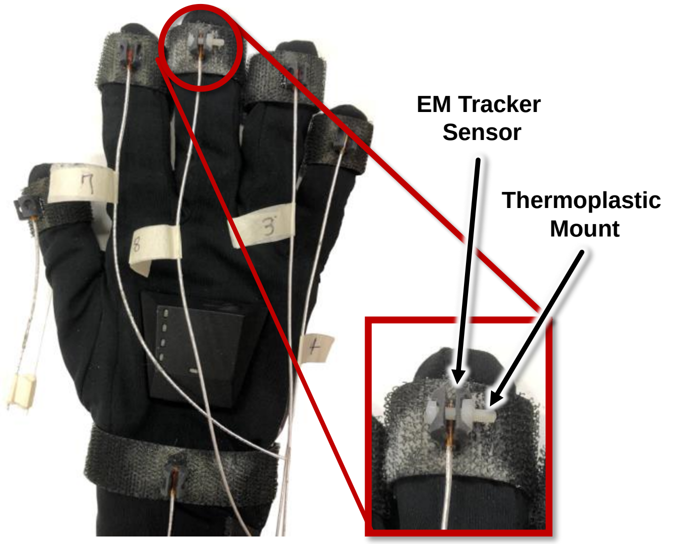

FIGURE 2: SENSORIZED GLOVE SYSTEM. ZOOMED-IN IMAGE OF THE MIDDLE FINGER SHOWS THE TRACKER SENSOR MOUNTED ON A THERMOPLASTIC ELASTOMER MOUNT, FASTENED WITH A NYLON SCREW TO PREVENT ELECTROMAGNETIC INTERFERENCE.

daily living objects given that the embedded sensors can change an object's surface texture and inertial properties. In addition, the size of the force or pressure sensors, combined with the geometries and scales of certain objects (e.g. scissors, keys, pencils) pose mechanical challenges in sensor embedding.

The use of wearable sensors is another commonly explored approach to the evaluation grasp function and hand impairment. Commercially available devices like the CyberGlove system provide real-time finger joint angle measurements that enable the characterization of grasp kinematics [9]. There are multiple studies on developing wearable, low-profile force or pressure sensing glove systems using components like force sensitive resistors (FSR), fiber optic sensors, and light-emitting diodes (LED) [10]. Commercial-off-the-shelf (COTS) devices are also available, like the Tekscan's Grip$^{\text{TM}}$ system, where contact forces across the fingers and the palmar side of the hand can be measured to quantify grip strength [11]. However, few researchers have explored simultaneous measurement of kinetic and kinematic grasp information during activities of daily living [5], and none to our knowledge have explored graphical representations of grasp data in real-time.

This work presents a grasp characterization system that can measure both hand pose and contact forces, and provides graphical representations of the kinematics and dynamics of grasps performed during activities of daily living. The objective of this work is provide physicians and therapists with an objective, quantitative means of assessing the hand function of patients affected by strokes and other motor impairment causing injuries and diseases. Successful implementation of this system could lead to the creation of a global grasp database system that, with the help of machine learning, could enable computer-assisted assessments of hand function or impairment and correlations with underlying conditions. The resulting grasp data can also be used as an empirical baseline for the development of more effective upper-extremity prostheses.

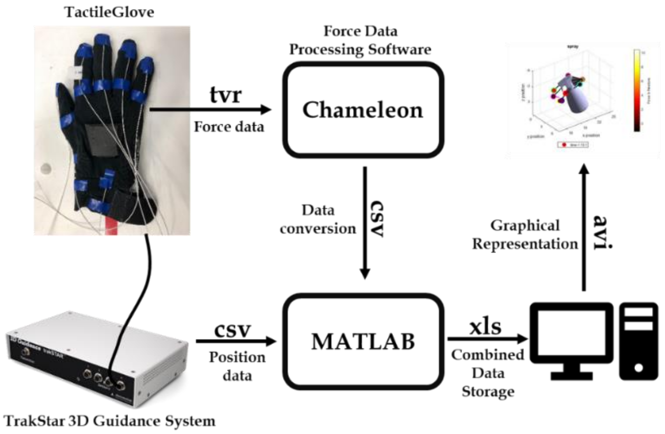

FIGURE 3: FLOW DIAGRAM OF DATA TRANSFER WITHIN THE GRASP CHARACTERIZATION SYSTEM

2. MATERIALS AND METHODS

The presented system characterizes human grasps by recording kinematic information of the distal phalanx and dynamic information at several contact points on the fingers and palm. The minimum dataset required for characterization includes: fingertip displacements (five positions plus one for thumb base) and wrist position, the position of the object during grasp, and pressure distribution across the palmar side of the hand.

2.1 Experimental Apparatus

We utilized an electromagnetic tracking system, (TrakStar 3D Guidance System, Ascension Technology Corporation) to tracking fingertips and wrist locations during object grasping. A total of eight trackers are used: five for fingertips, one for the thumb base, one for the wrist, and one for the object location and orientation. The system measures the Cartesian coordinates and Euler angles of the trackers with respect to its electromagnetic transmitter at a rate of 80 Hz—which seems sufficient given that a similar study that analyzes handshapes using the Cyberglove uses joint angle data sampled at 50 Hz [8]. The angles are used to obtain the normal directions of the contact forces with respect to the force sensors.

The force distribution across the palmer surface of the hand is measured using the TactileGlove developed by Pressure Profile system. It consists of 52 capacitive pressure sensors embedded inside a nylon fabric glove. Pressure distribution data is communicated via a Bluetooth dongle at a rate of 40 Hz. The glove is designed for a right-hand dominant user; thus, subjects were limited to being right-hand dominant with hand sizes within the threshold range for the size of the glove. The electromagnetic trackers were mounted on the dorsal portion of the glove using

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TABLE 1: LIST OF ALL OBJECTS USED AND TASKS PERFORMED WITH EACH OBJECT.

Object	Task Performed
Door lever	Making three or four rotations of the lever and pulling it for each rotation
Kitchen spoon	Making three or four scoops of fictitious food on a plate
Wine glass	Taking three or four sips continuously
Screwdriver	Pressing the head down on the table and making three or four rotations
Squeeze bottle	Squeezing three or four times with head facing down
Tumbler	Taking three or four sips continuously
Peeler	Making three or four efforts to scratch the surface of an imitation pear
Cube	Grabbing from two different sides and holding it from top and bottom
Pen	Writing down notes on a paper after removing its cap
Coffee mug	Taking three or four sips continuously
Bowl	Holding it up and pouring its fictitious content on the table
Notebook	Holding it while flipping its pages with the left hand
Key	Inserting into a pretend keyhole and make 3 easy efforts to twist
Comb	Making brushing motions on a sleeve
Lid of a jar	Loosening a tightly fastened lid; then, fastening it back on the jar
Dust brush	Grabbing the brush by the handle and pretending to sweep a pile of dust into a dustpan
Measuring cup	Making three or four pretend scoops from a fictitious pile of grain
Whiskey	Taking three or four sips continuously
Toothbrush	Performing normal brushing motions on the left hand
Knife	Cutting three or four pieces of a plastic tube
Tennis ball	Tossing up three or four times with palm facing up
Hammer	Hammering a nail to drive it incrementally into a wood board
CD	Holding it by the rim and the hole
Fork	Picking fictitious food placed on a plate
Milk carton	Pouring water inside of the carton into a cup
Spray	Spraying water onto a cloth using the lever
Beer bottle	Taking three or four sips continuously
Game controller	Pressing buttons like playing a video game
Cereal box	Pretending to pour cereal into a bowl
Dish	Holding it in air and rotating it
Book	Holding it while flipping its pages with the left hand
Espresso cup	Taking three or four sips continuously
Tape roll	Rolling it on the table three or four times
Credit card	Performing a card swipe on a card reader
Spoon	Making three or four scoops of fictitious food on a plate
Mouse	Performing operations typical with an office mouse

custom 3D printed PLA mounts with nylon screws to fasten the trackers on the mounts while avoiding electromagnetic interferences as shown in Figure 2. Benchtop tests demonstrated that there were negligible levels of electromagnetic interference (normalized error < 5%) between the TrakStar system and the TactileGlove.

2.2 Human Subject Study

To evaluate the combined EM tracker and pressure glove system, we developed a study where human subjects perform various grasping tasks while timestamped position and pressure data are collected. Inclusion of subjects was limited to those that are right-hand dominant and have hand sizes of wrist to middle fingertip length between 18 to 21 cm and circumference around the knuckles of 18 to 22 cm. Subjects were provided with the characterization glove and 10 random objects from a pool of 36, listed in Table 1, and were asked to perform tasks typically associated with each object like tossing the tennis ball or swiping the credit card on a reader. The experimental protocol for the study included the following steps:

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- Subjects are briefed about the protocols and process of the study as well as the precautions to take for safety and proper measurement (lasting ~10 min.),
- Subjects are asked to wear the provided motion/force tracking glove and are given a training period for using the glove to manipulate the objects without tampering the sensor readings (~15 min.),
- For each object, subjects perform the tasks specific to that object for approximately 30 seconds (~15 min.),
- Data are recorded and saved to archive after each grasping task; the EM tracker on the object is removed and replaced on a new object after each run (~10 min.),
- Subjects take a survey relating to their experience during the study and provide feedback (~10 min.).

The experiment lasted approximately one hour, in total. Nine subjects participated in the study, and all experimental procedures were approved by the Georgia Institute of Technology Institutional Review Board.

2.3 Graphical Representation

The data collected from human subject trials were used to generate animations that reenact the motions and dynamics of object manipulation. To synchronize the timestamps between the force data and the position data (as the TactileGlove and the TrakStar are two separate systems), subjects were asked to make a pinching motion before conducting each grasping task to match the initial time based on the minimum threshold distance and the threshold pressure values between the index and the thumb. As the two systems had differing sampling frequencies (80 Hz for the TrakStar, 40 Hz for the TactileGlove), force data were interpolated based on the timestamps of the position data to generate a smooth graphical representation for intuitiveness and ease of interpretation. To generate a simple model of the hand with information about its configuration, as shown in Figure 4, the palmar section of the hand is represented with a gray-filled tringle, circles with different outline colors represent the contact point locations, and lines connecting certain circles and the triangle show one-degree linkage representation between the

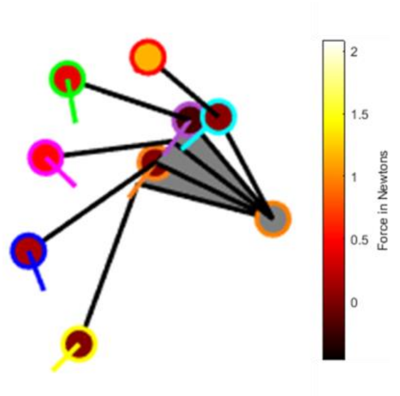

FIGURE 4: SKELETAL REPRESENTATION OF THE HAND WITH INFILLS REPRESENTING FORCE MAGNITUDES. THE COLORBAR ON THE RIGHT DISPLAYS FORCE VALUES AT DIFFERENT COLORS. OUTLINE COLORS OF THE CIRCLES REPRESENT CONTACT POINT LOCATIONS WITH THUMB, INDEX, MIDDLE, RING, LITTLE FINGERS BEING RED, GREEN, MAGENTA, BLUE, AND YELLOW RESPECTIVELY.

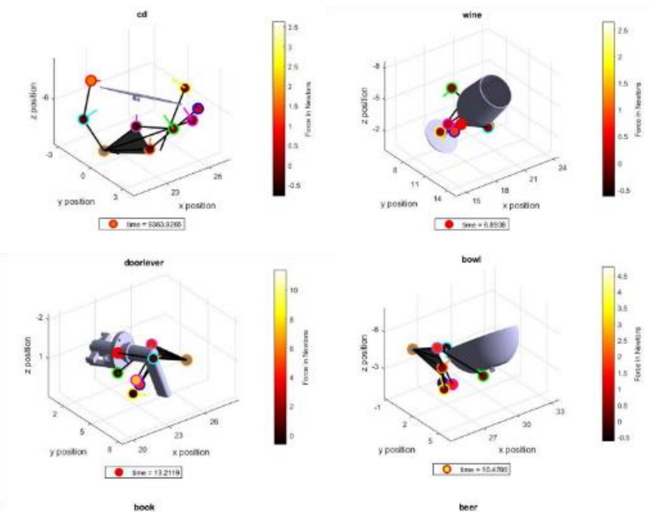

FIGURE 5: FRAMES OF GRAPHICAL REPRESENTATION OF GRASPING TASKS BY HUMAN SUBJECTS. A SKELETAL REPRESENTATION OF THE HAND ALLOWS EASY VISUALIZATION OF DIFFERENT HAND CONFIGURATIONS. THE COLOR INFILLS AT CRITICAL LOCATIONS OF THE HAND ILLUSTRATE THE CONTACT DYNAMICS OF THE HAND DURING TASK PERFORMANCE.

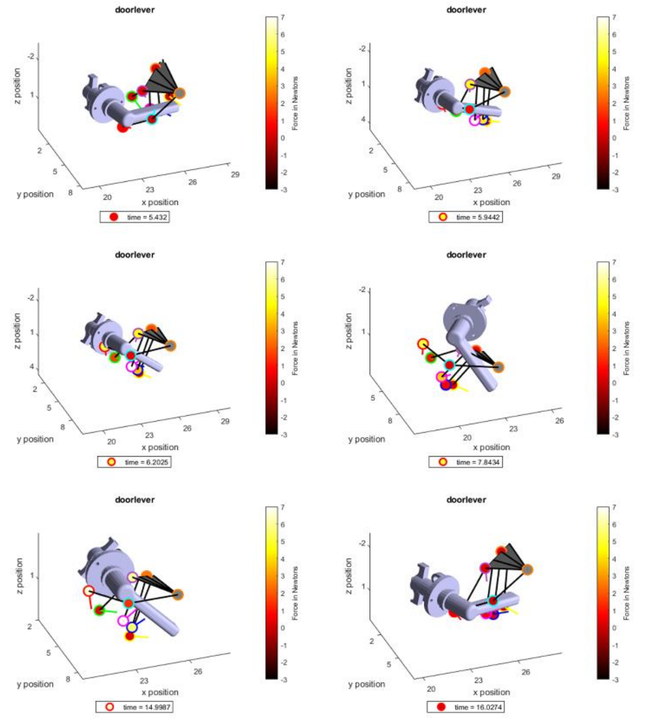

FIGURE 6: FRAMES OF GRAPHICAL REPRESENTATION OF GRASPING A DOORLEVER.

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fingers and the knuckles. Force values are represented with color infills at the contact locations and arrows with its length proportional to the contact force magnitude. The color infills at the contact points were mapped using a ‘hot’ colormap, where brighter colors correspond to higher values and darker colors correspond the lower values. The maxima and minima from each grasp trial were obtained to set the colormap limits. To demonstrate how the hand interacts with the objects, computer aided design models were generated in STL format and imported to MATLAB, with the orientation and position of each object retrieved from the EM tracker data from the study.

3. RESULTS AND DISCUSSION

We obtained data from nine subjects, with ten trials performed by each subject. The resulting grasp database consists of 90 video files of 36 objects, totaling 45 minutes’ worth of data. Frames obtained from some of the generated animations are displayed in Figures 5 and 6. The execution time to generate animated models for nine subjects was approximately 15 minutes, (1.67 minutes per subject), and the entire file size including raw data, CAD models, and video files totaled 2.91 GB (324 MB per subject). The system can generate simplistic and informative graphical representation of the grasping tasks with 324 MB worth of data within 62 minutes (60 minutes of data collection and two minutes of graphics generation) per subject. The frame rate for the animated models is high enough to illustrate, in detail, the low-bandwidth interactions associated with normal usage models for objects of daily living, but not high enough to register events such as object slip and vibration, which have frequency components in the 100’s to 1000’s of Hz.

Though we used the TactileGlove system and the TrakStar 3D guidance system for our grasp characterization system, there are several alternatives to measuring the kinetics and kinematics of grasping, including using commercially available low-cost bend sensors and force sensitive resistors. However, these low-cost alternatives tend to be more susceptible to thermal drift and electromagnetic interferences than the systems we employed.

4. CONCLUSION

A grasp characterization platform was developed to measure the kinematics and kinetics human grasping as users manipulate various objects of daily living. This system uses a sensorized glove with embedded capacitive force sensors and electromagnetic 3D motion tracking to acquire grasp data, includes graphics generator to visualize the mechanics of object grasping in real-time or offline. With this system, physicians and therapists may one day be able to diagnose hand impairments faster and more accurately using objective, data-driven approaches which provide a stronger intuition of the patients’ grasping capabilities. Furthermore, physicians can utilize the characterization glove to develop a quantitative kinematic and kinetic modeling of the patient’s hand compared to the traditional methods to design a personalized therapeutic program for each patient. More applications of this system include facilitating grasp analyses for sports therapy, creating simulations of postural synergies for the design optimization of manual tools, and creating an empirical basis for the design of patient-specific powered robotic prostheses.

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