Dexterous Lab: Motion Tracking and Quantitative Analysis for Patients with Cerebral Palsy

1 Background and Problem Statement

1.1 Cerebral Palsy

Cerebral Palsy (CP) is a chronic neurological disorder that affects 500,000 Americans. The range and severity of symptoms range from patient to patient, but typically the disorder is characterized by various forms of physical impairments. While there is no cure for CP, there are many types of treatments that can help patients improve their motor skills. However, doctors and therapists have extremely limited tools for assessing the effectiveness of their treatments over time.

1.2 Limitations of Functional Dexterity Test

The Functional Dexterity Test (FDT) is a common and reliable way for physicians to measure the dexterity of their patients. The test is simple, cheap, and easy to administer. Patients are simply asked to pick up small wooden pegs and move them in a designated way, including rotating them by fingers. The administrators simply observe the patient and record the amount of time it takes to complete the task. While this data is to some extent helpful, large amounts of helpful quantitative data that capture unique details of a given patient's condition are lost.

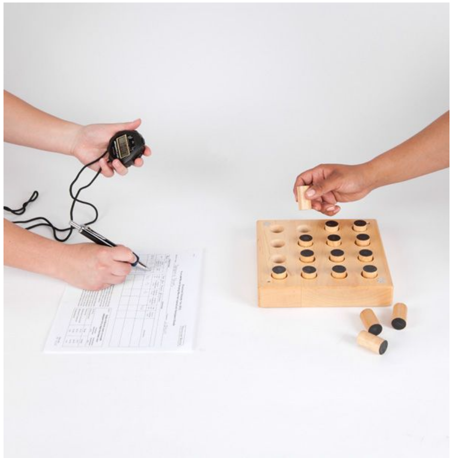

Figure 1: Patient performing Functional Dexterity Test

1.3 Project Goal

Therefore, we have developed a system that accurately and reliably captures quantitative data by tracking and reconstructing the path taken by the individual pegs during the Functional Dexterity Test. Our product will give doctors and therapists an extremely useful tool in understanding exactly how their treatments are affecting their patients in a highly analytical and quantitative sense.

2 Current Technologies and the Design Process

When we began the design process, we looked toward popular commercial methods for object recognition and tracking. It quickly became clear that there is only one full solution that could gather the type of data we wanted. Motion Labs are popular for tracking full body motion of both patients and actors (for use in CGI, like Gollum from Lord of the Rings). While they do have the ability to accurately track the movement of patients, they are extremely limited in availability, and are very expensive to build, maintain, and operate. However we did take inspiration from their overall design. A series of cameras are placed around the room, which then are able to focus in on reflective orbs placed on the patients. IR technology is then used to localize the orbs either via time-of-flight or stereo-vision method. This pointed us in the direction of various tools we could use to accomplish our goals.

There are already several popular and functional motion tracking devices in the market, including the Microsoft Kinect, LeapMotion, and Intel Real Sense. The Kinect appears in our final solution due to its versatility as well as its development tools. It contains both an IR camera and a standard HD RGB camera, giving a wealth of visual data to work with. The RealSense requires the newest generation of Intel processors to operate, making it difficult to design with and implement. And finally, the Leap Motion lacks the color camera of the Kinect and the types of development tools needed to integrate it into a full system.

Another major component of the solution came from previous attempts at completing this capstone project. Previous teams outfitted the pegs with Inertial Measurement Units, which contain a combination of accelerometers, gyroscopes, and a magnetometer and can output angular velocity and acceleration. This data can then be used to calculate orientation and position of whatever object the IMU is fixed to. While accurate over short periods, the calculation methods necessary to obtain position introduce large errors over time, rendering the solutions ultimately ineffective. However the idea of placing an IMU within the peg proved to be valuable in a few ways. Most importantly, we were able to accurately and continually calculate the orientation of the peg over time via an IMU lodged within the peg.

3 Final Design: Integration of Kinect, IMU, and Statistical Learning Methods

Our solution works in 3 distinct phases. First, a series of calibrations and tests are run in order to ensure the system is working properly. Then, the patient begins the test, and both the Kinect and IMU record data. Finally, this data is combined and run through a smoothing spline fitting model before being plotted in a 3-D graph.

3.1 Peg Recognition

The peg is outfitted with sections of different colored neon tapes, bounded by reflective tape. The Kinect uses its IR camera to recognize the peg. The black backdrop ensures that the reflective tape on peg is the only reflective object in the frame. Our algorithm then maps the coordinates from the IR image to the corresponding region in the RGB color image. We chose the four colors below because they have high contrast between each other, as well as high contrast with human skin. A major challenge we faced over the course of the project was occlusion, which happens when the patients' hands cover up part, or all of the peg, limiting the Kinect's ability to recognize the peg. The colored sections are a major part of our solution to this issue. With the colored sections, the kinect only needs to be able to see 10 pixels of the same color to be able to determine where the entire peg is. The software knows where the sections are relative to each other, and uses angles from the IMU to accurately calculate the center of the peg.

Figure 2. Exterior Peg Design

3.2 IMU data

Instead of the original wooden pegs, we 3D printed new pegs that have a hollow interior so that we can fix a WiFi enabled Arduino board and an imu in place within the peg. The raw data is then streamed to the main control laptop via WiFi, where it is used to calculate the orientation of the peg.

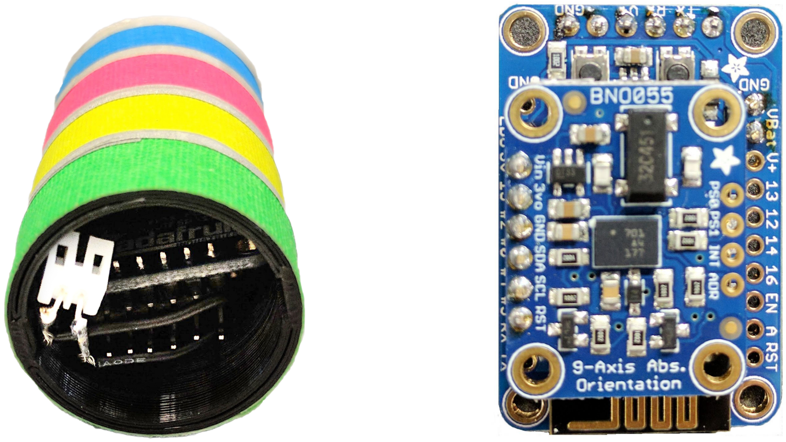

Figure 3. Interior peg design (left) and IMU hardware (right)

3.3 Post Processing of Data

In some cases, the Kinect might not be able to accurately give coordinates of the peg. In these situations, we use the smoothing spline algorithm to predict the coordinates in the missing frame. The smoothing spline algorithm basically fits a curve that follows the trend in the observed data as closely as possible while making sure the curve is smooth. Additionally, the graphical user interface has the option to display the orientation data in conjunction with the coordinates.

3.4 System Setup

As shown below, the final system involves a laptop with all necessary software installed, the Kinect plugged into the laptop, and a patient holding a peg. The test administrator interacts with the system via the graphical user interface, which allows for easy calibration and data collection.

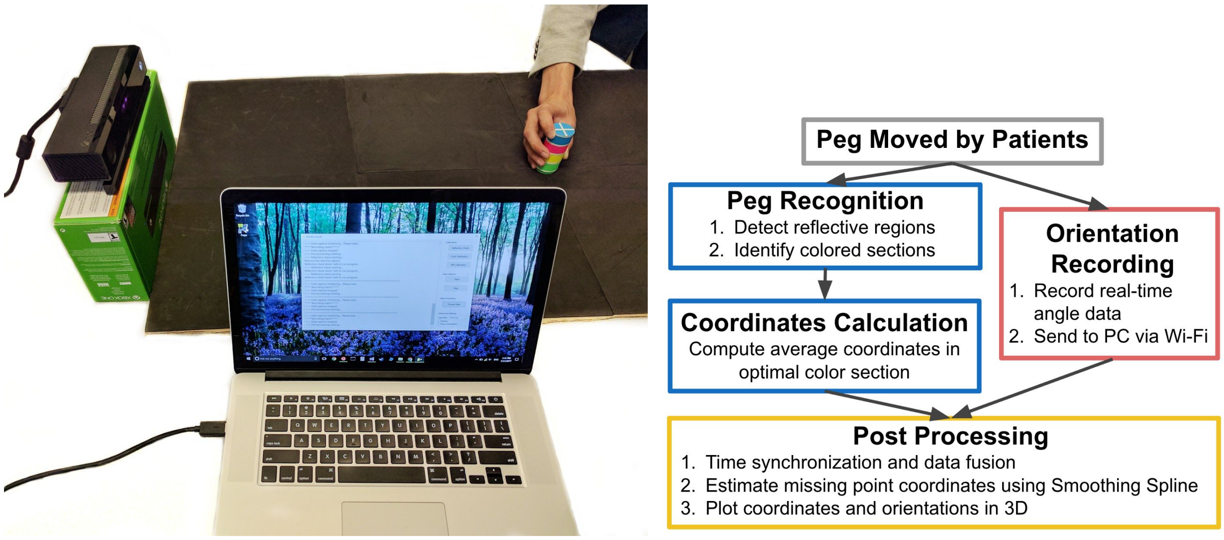

Figure 5. Full Prototype (left) and Data Flow (right)

4 Results and Testing

Various experiments have shown that we were able to achieve an average error of less than 1 cm, in both cases. We tested full Kinect functionality by comparing our data with closely monitored robotic movements at a fixed distance from the Kinect. To test the efficacy of our smoothing spline algorithm, we ran simulations where we randomly removed several points from the data stream and pretended that these points were missing. Then we used the smoothing spline algorithm to predict these coordinates and compared the predicted coordinates to the actual coordinates.

Most importantly, we have been able to begin using our device to test patients, and plan to install our software at Shriner's Children's Hospital and have them test a wide variety of patients over the next few months.

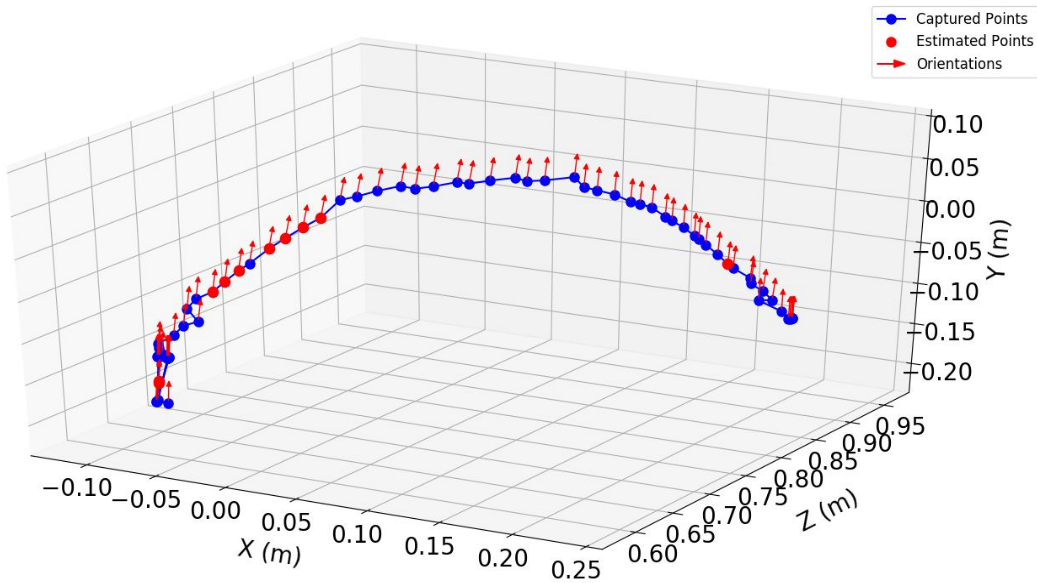

Figure 6. Sample Output Data

5 A Low Cost Solution

The major components of our system are the microsoft Kinect (without Xbox) that cost $150, a few breakout boards for the Arduino system that cost $80 in total, and finally the peg itself. The total cost of these components is around $250. This prototype will be donated to Shriner's Hospital for Children and we are still considering options to commercialize the product.

6 Outcomes and Significance

Once we deliver our device to our sponsor, Dr. Gloria Gogola, she plans to gather a large amount of data to look for trends across different groups of patients. In the long term, this data could help improve treatment for patients with various diseases and disorders that affect motor abilities. In conclusion, we have developed a motion tracking device that is used to further quantify the results of the Functional Dexterity Test, and thus give doctors a better tool to assess their treatments in patients with Cerebral Palsy and other diseases that affect motor abilities.

7 References and Acknowledgements

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