Characterization of Gait Patterns in Common Gait Rehabilitation Exercises

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Abstract—Gait training is an important part of recovery from stroke or surgery, or treatment for neurological disorders such as Parkinson's disease or Multiple Sclerosis. A gait monitor that uses infrared sensing technology has been developed at RIT and proven to successfully monitor an individual's walking patterns over a variety of different terrain types. Based on observations at a local physical therapy clinic, additional rehabilitation activities have been identified and measured, and will be presented in this poster. The RIT gait monitor has been used to quantify walking patterns for individuals with no known gait abnormalities doing (1) backwards walking, (2) side-stepping, and (3) walking up and down stairs in a step-by-step pattern. The gait patterns found are distinct from normal level ground walking and traditional step-over-step stair ascent and descent, thus demonstrating this device's utility as a gait monitor in these unique walking scenarios.

Keywords—gait, rehabilitation

I. BACKGROUND

Millions of people in the United States alone undergo some type of gait-related rehabilitation each year [1, 2]. This may be a result of physical conditions, such as total knee or hip arthroplasty, lower limb amputation, or injury. Gait rehabilitation or training may also be a part of the treatment for neurological conditions such as stroke, Multiple Sclerosis, Parkinson's Disease, Charcot-Marie Tooth Disease, or Cerebral Palsy. In all cases, clinicians require a tool to characterize gait and measure changes in client gait patterns, both for therapeutic reasons and for insurance purposes.

In prior work done at RIT, a wearable, portable gait monitor was developed [3, 4]. The device (Figure 1) uses an infrared proximity sensor to look ahead of the user at the upcoming ground. Using the patterns in the sensor data captured during walking, the system is capable of quantifying client gait patterns over level ground, up and down ramps, and up and down stairs (step-over-step pattern). This is done by fitting a 4th order Fourier series, scalable in order to account for differences in gait speed, to the data. Figure 2 shows representative gait data for a single subject over the five different terrain types. The ability to capture and characterize the types of walking that occur during community ambulation will enable clinicians to assess a client’s ability to return to more independent living scenarios [5-10].

Besides the types of walking done at home and in the community, clients undergoing gait rehabilitation may practice other types of walking during rehabilitation. In the course of observations at a local physical therapy clinic that serves individuals with neuromuscular disorders, clients performed backward walking exercises and side-step exercises in addition to traditional forward gait. Additionally, some clients traverse stairs in a step-to-step (or “tap-step”) pattern, rather than step-over-step [11]. While step-to-step stair traverses are not ideal, they are a means for someone with gait abnormalities to successfully use stairs. The RIT gait and terrain monitor is a good candidate to quantify and track these types of gait
patterns in addition to those found in typical community ambulation.

The goal of this study was to determine whether the RIT gait monitor is capable of capturing a distinct gait pattern for a series of walking patterns that are similar to, but not exactly the same as, the type of walking done on an every day basis by people with no known gait abnormalities.

II. DATA COLLECTION & ANALYSIS

A. Equipment

The system shown in Figure 1 is based on two Sharp GP2Y0A02YK IR proximity sensors, one looking forward at the upcoming terrain and one looking down toward the ground. The sensors are connected to an Arduino Uno microcontroller with removable flash memory for data storage, powered by a 9V battery. The sensors have a useful range of 10-80 cm, corresponding to a range of 2.75-0.4 V (i.e., shorter distance = higher voltage).

B. Data collection

Two individuals with no known gait abnormalities performed a series of walking exercises using the RIT gait and terrain monitor. The trials included backward walking, sidestep, step-to-step stair ascent, and step-to-step stair descent. The sidestep and stair ascent/descent trials were performed both with the instrumented leg leading and the non-instrumented leg leading, since both scenarios can occur during rehabilitation. A summary of trials is presented in Table 1. A typical gait period for the subjects in this study was approximately 1-1.2 sec (0.83-1 Hz), and the data are being fit to a 4th order Fourier series (i.e., the highest frequency content being identified would be 4 Hz). The IR sensors require approximately 40 ms (25 Hz) to acquire a signal, so data were sampled between 8 and 25 Hz in order to satisfy the Nyquist rate and avoid oversampling.

C. Data Analysis

All data were fit to 4th order Fourier series using a RANSAC-based algorithm [12]. The lower sensor shown in Figure 1 is used to establish a common starting point for each step: when the sensor value is minimum, i.e. a point in the gait cycle very near heelstrike, a new step starts. The coefficients were fit for each individual step, then averaged over all of the steps taken in a particular trial. For example, four trials on a 13-step flight of stairs would result in 52 steps to fit. Since a Fourier series is scalable in time, variations in frequency will not impact the shape of the Fourier series as long as the basic mode of walking is consistent.

III. RESULTS AND DISCUSSION

A. Level Ground: Backward and Sidestep

For scenarios occurring on level ground (backward walking and sidestepping), distinct gait patterns were found in the data. All curves were generated using the average Fourier coefficients fit to each of the individual steps described in Table 1. Figure 3 shows the Fourier series fits to backward walking from this study, compared with forward walking on level ground from [4]. The different patterns are visibly different, which will allow a clinician to distinguish different walking exercises from a client’s data. Similarly, Figure 4 shows the results of sidestepping exercises. The plot compares the gait patterns found with the instrumented leg leading and with the non-instrumented leg leading. Again, there is a visible distinction between the two activities. Finally, Figure 5 shows all level ground scenarios on a single plot, which demonstrates the distinct differences between each scenario when examining the IR sensor data.

<table>
<thead>
<tr>
<th>Test</th>
<th>Duration</th>
<th>Leading leg</th>
<th># trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backward walking</td>
<td>100 feet</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td>Sidestep</td>
<td>50 feet</td>
<td>Instrumented</td>
<td>3</td>
</tr>
<tr>
<td>Sidestep</td>
<td>50 feet</td>
<td>Non-instrumented</td>
<td>3</td>
</tr>
<tr>
<td>Upstairs (step-to-step)</td>
<td>13 steps per flight</td>
<td>Instrumented</td>
<td>4</td>
</tr>
<tr>
<td>Upstairs (step-to-step)</td>
<td>13 steps per flight</td>
<td>Non-instrumented</td>
<td>4</td>
</tr>
<tr>
<td>Downstairs (step-to-step)</td>
<td>13 steps per flight</td>
<td>Instrumented</td>
<td>4</td>
</tr>
<tr>
<td>Downstairs (step-to-step)</td>
<td>13 steps per flight</td>
<td>Non-instrumented</td>
<td>4</td>
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</tbody>
</table>
B. Ascending and Descending Stairs

For the four stair scenarios investigated, up and down, with the instrumented leg leading and following, distinctly different gait patterns were found. Figures 6 and 7 show the results from stair ascents and stair descents, respectively. In each case, the step-to-step pattern is visibly different from the step-over-step approach that is found in normal gait. Additionally, the results when the instrumented leg leads are different from the results when the non-instrumented leg leads. This distinction is important when training a client to use an “up with the good, down with the bad” step-to-step walking pattern, as this gait monitor can track whether the user is using the correct leg to lead when walking on stairs.

The downstairs data show an interesting feature when the instrumented leg leads. As shown in Figure 8, a representative raw data set from one trial, the local minimum in each step varies over the length of the stairsway, with the minimum IR sensor reading steadily increasing. The minima in the data correspond to the points in the gait cycle when the ground is farthest away from the sensor. When the user is standing near the top of the stairs, the sensor is directed ahead of the user and picks up no ground. Therefore, the sensor reading is expected to be at a minimum. As the user descends the flight of stairs, the IR sensor looking out ahead begins to register the ground at the bottom of the stairs, getting closer to it with each passing step. As the ground gets closer, the IR sensor readings should increase, which they clearly do in Figure 8. While the RIT monitor has been tested for its ability to quantitatively capture many different terrain types, transitions from one type to the next can still be challenging. The observations from this study provide one means by which a transition can be detected.

IV. CONCLUSIONS AND FUTURE WORK

The results presented here demonstrate that the RIT gait and terrain monitor has the potential to be used for nontraditional walking exercises such as those performed during a rehabilitation session. Another application would be determining whether clients are using the appropriate techniques to ascend and descend stairs.

ACKNOWLEDGMENT
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REFERENCES

[1] Centers for Disease Control and Prevention 2010, "Number of All-Listed Procedures for Discharges from Short-Stay Hospitals, by Procedure Category and Age."