Taking Steps to Monitor Health

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Introduction

The metrics behind walking tell many hidden stories about an individual's health.

While a visibly noticeable limp is an obvious indicator of injury, subtle changes in gait can inform health in countless ways. For instance, gait can be used to characterize occurrence of musculoskeletal injuries, the progression of neurodegenerative diseases like Parkinson's, and likelihood of falling for older adults (Rampp, 2015).

Wearable sensor systems are a breakthrough technology that enable long-term monitoring beyond traditional gait analysis methods conducted in a lab. Decades of growing research have found many places where sensors can be placed on the human body to measure the movement in gait (Tao, 2012).

While sensors are the foundation, a finished end product shows the gait analysis results in a user application with user-friendly visualizations. In between the initial data collection and the user application, the data get stored in a database and analyzed using signal processing algorithms. Wireless connectivity ties together the communication needed between devices to create a wearable Internet of Things (IoT) system.

Team Cerulean 2019 at Tufts University created a prototype for tracking health in military trainees prone to musculoskeletal injury (MSI) due to long treks in training (Williamson, 2016). A wireless wearable device is needed to collect gait data in the outdoor training environment. The team interviewed military medics to understand how real-world users would use such a device. Given that the medics did not have specific knowledge for interpreting gait data like a physical therapist would, the prototype shows quantifiable changes in gait that are meaningful to non-experts.

Background

Gait Metrics

Human walking is a periodic movement characterized by gait parameters and phases. A healthy individual is expected to have a relatively symmetric gait cycle (Parry, 2014).

A stride is a complete gait cycle, such as when a foot hits the ground once to when it hits the ground again. A cycle can be divided into two major phases, the stance period and swing period, to describe the points in movement when, respectively, a foot is grounded and when a foot is in the air. Figure 1 shows an example. The stance period begins at initial contact from a foot while the swing phase begins at toe-off. Typically, the stance period is 60% of the gait cycle while the swing period is 40%. The cycle is often divided into eight phases of movement in total, each of which belong in either the stance or swing period.

Gait parameters are either temporal, varying in time, or spatial, varying in space. Current research investigates computational methods to identify gait phases and calculate gait parameters from sensor data. Drastic changes in these gait metrics or gait asymmetry indicate important changes in health.

Figure 1. Stance period (left) and swing period (right) of the right leg

Examples of temporal parameters

- Cadence: the number of steps per unit time
- Speed: the distance walked per unit time
- Stride time: the time taken for a stride
- Single limb support: the percent of time where weight is on a limb compared to the total gait cycle time

Examples of spatial parameters

- Step length: the distance between two consecutive steps from the heel contact of one foot to that of the opposite foot
- Stride length: the distance of a stride

Gait Analysis

After sensors measure the acceleration of a person walking over time, the noise from the raw measurements must be smoothed out using filtering techniques. Then, the filtered values and their timestamps are used to compute gait metrics.

Many spatiotemporal gait parameters can be calculated from acceleration data because gait is periodic, meaning that the data contain a repeating pattern over time. Every stride creates one occurrence of the pattern, so someone walking regularly for many steps creates consecutive repeats of this pattern. The time it takes for the pattern to repeat is the stride time. The acceleration data is used to find the stride length.

Gait phase detection is an open-ended problem with solutions from many approaches ranging in complexity (Rueterbories, 2010). In general, the gait phases are identified by matching the gait phase with the corresponding behavior exhibited in data. Gait phase identification can be modeled as a supervised machine learning problem. That is, every type of phase identification algorithm learns from data where the correct phases are already known to identify phases in other data where the phases are unknown.

Prototype Design

The team's prototype is a system connecting a wearable hardware device, a database server with gait analysis capabilities, and a user application. The purpose of a physical device is to gather acceleration data from sensors to send to the database.

Hardware

A user wears a device on each ankle using Velcro straps, as shown in Figure 2. As the user walks, inertial sensors measure rotational and translational acceleration data along three axes. A microcontroller

Figure 2. Prototyped device case containing battery and circuit worn on ankle

receives the raw sensor values via wired communication and offloads the data wirelessly, via Wi-Fi, to a Raspberry Pi. From the Pi, the data are sent to the database for processing, ready to be shown through an application upon user request.

Conclusion

This design allows medics to monitor the health of trainees. The most critical feature of the prototype to be implemented next is long-term use capability where technical factors include battery life, network connectivity, sensor accuracy, and synchronization.

While this design prioritized the detection of musculoskeletal injury, it can be expanded for other applications. Typically, different applications may require different sensor placement, gait metrics, and analysis techniques. However, it may also be worthwhile to explore the design of a general device for a variety of purposes in a commercial, rehabilitative, or research space.

References

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