Modelling Human Activity Through Structural Vibrations with Alternate Computational Devices to Increase Cost Efficiency

Elaine Patterson

Spring Valley High School, Columbia, SC

Every event that occurs has a reaction, whether it be a pebble causing ripples in a pond or a bullet distressing a wall. Within a structure, these vibrations caused by a specific event in a medium can be measured with an accelerometer, and just as the vibrations caused by a bullet differ observably from those caused by a pebble, vibrations caused by walking vary from those caused by falling, running or jumping. To the eye, these differences are slight to severe, but when that signal is dissected, it is identifiable by its cause and location with extensive applications from home security to commercial monitoring of foot traffic to behavior analysis for medical care including fall detection. The focus of this study was to investigate how this signal is collected -- specifically, if a cheaper independent computer could replace a setup that currently costs thousands. The Raspberry Pi was used with an ADXL345 accelerometer as this alternate system. This study includes notes of development of the hardware and software as well as analysis of the developed system by comparison to the accepted system. The new system is enabled to continuously read the accelerometer’s z axis output value, maintaining a buffer and saving significant signals. These hypothesized capabilities were confirmed by collecting vibration data from the same impact and comparing how each system recorded the event.

Introduction

Accelerometers can be found in many different forms, each serving a variety of purposes. Compact, low sensitivity versions are used to play games on smartphones. More advanced accelerometers are used to monitor the state of gearboxes and drivetrains in vehicles ranging from minivans to helicopters. Even more accelerometers are used to monitor seismic activity, collecting data during, before and after earthquakes. All of these systems monitor vibrations relative to some media: a phone, a shaft, or the Earth. And each of these systems uses an accelerometer specialized for the types of data that it collects. An in-phone accelerometer does not need to be as precise as a shaft accelerometer in a helicopter, but it needs to be much cheaper. A seismic sensor needs to be able to collect signals of great amplitude, and they can be more expensive.

For this experiment, these powerful and versatile devices were used to monitor structural vibrations within a room. These structural vibrations can be interpreted to show the behavior of their user. The goal to monitor behavior is rooted in finding how walking and falling are different in effect and determining an effective way to record events such as these live, calling attention to events that suggest a specific action has occurred, whether that be a fall, a security threat or other irregular activity. A commercial structural monitoring system like these must be more reliable than a smartphone accelerometer yet cheaper than an industrial grade seismic activity monitor. Falling, for example, is a leading cause for distress among the elderly. According to the World Health Organization (2012), 37.3 million falls that result in the need for medical care occur annually. Of these falls, over an estimated 400 thousand are fatal. An increasingly recognized solution to the problem of low height falls among the elderly is the incorporation of automated fall detection systems into homes and hospitals. These fall detection systems aim to decrease the time that a victim of a fall rests on the floor before getting help. This period of time the person remains without help is commonly known as the ‘long lie’ and is known to cause many long-term injuries; these include hypothermia, pneumonia, dehydration, and other complications that eventually lead to death for many who suffer them as result of a fall. Most fall related fatalities occur because of trouble encountered during the long lie. Shortening or eliminating this time period would significantly reduce the fatality of falls thus the fear of falling. Even elderly who have not fallen suffer from the condition of fear. They reduce their physical activity in their homes because they worry that movement will lead to a fall. A system designed to address this problem must be prepared to approach the physical and psychological side of it because the user’s outlook on the situation will greatly affect their activity levels. People with lower activity levels may suffer from decreased blood pressure, obesity, weakened bones, and weakened skin. All of these are to be avoided, and many methods have been proposed to do this: Madarshahian et al. (2014) proposed a Dynamic Time Reversal method, Kangas et al. (2009) proposed a simpler approach aimed for compatibility with waist-worn accelerometers, Medrano et al. (2014) proposed an algorithm compatible with most smartphones, Cucchiara et al. (2007) studied an approach using cameras, and many more have followed. Each of these have their own flaws, ranging from a lack of privacy to an expensive setup and maintenance.

Another popular current solution follows the Life Alert model, but often because of a fall, the victim is incapacitated and unable to call for help, or because of a mental illness such as dementia, the wearer is unable to recall the device. In either situation, such a device is useless. Not only does an accelerometer system avoid these mentioned issues, but it also serves more than one purpose. As mentioned before, this system could also monitor for irregular activity. While one of these irregular activities is a fall, another example is this: an early sign of dementia is getting out of bed and walking around often in the middle of the night. With the user’s consent, information like this could be monitored by family or health professionals. Other irregular activity could be this: say the user input a time when they were out of town, or the system noticed a time when there was low activity (suggesting that no one was normally in the house). Activity in this time could alert the user, the user’s family or law enforcement of a problem.

The ultimate goal of this research was to have a system that can reliably and affordably monitor behaviors like these using accelerometers to measure structural vibrations, reporting incidents such as falls or continued irregular behavior when necessary. To reach this goal, a system analogous to those used in past studies was made using a Raspberry Pi and an ADXL345 (an accelerometer) created for the Pi. This system costs about $100 per location (each location in this consists of a Pi and a sensor), resulting in a total system cost of about $300, versus the previously used system (each location in this consists of a sensor, and each location is linked to a single system computer) that costs about $1300 (assuming that there are 3 locations set up in the system). With a more affordable system, more people that need help can get it.

After the new system was created, software was developed to collect data like the previous system, and features were added that take advantage of having a fully operational computer at each location. The new system has the potential to detect and confirm an event by comparing sensor values at a given time, to run and record events indefinitely, to email notifications after an event has been detected, and to do countless more things as the software is further developed.
Methods

Before the accuracy of the system relative to its predecessor could be determined, the system had to be created -- the result of this hardware development is pictured in Figure 1. The ADXL345 accelerometer was soldered to the Adafruit proto plate. Key pins were connected via the green wire according to the leads described in figure 1. A GPIO connector carried signals from the proto plate to the computer itself.

After software was made to accompany this hardware and collect the data in a fashion similar to that used in Arocha et al. (2013), the signals had to be compared to ensure that the signals were similar. This was originally done by placing the old sensor directly beside the setup shown in Figure 1, but the ADXL345 was subject to more noise than the 333B50 because of its casing; to limit this factor, the 333B50 was moved onto the proto plate on a piece of masking tape (as shown in Figure 2). The signals collected were compared autonomously using a coherency function, and they were compared visually. To ensure that this comparison was made with the correct points, the signal obtained from the old system (using the more expensive accelerometer with a higher sampling frequency) was resampled so the difference in sampling frequency would not interrupt comparison. A simple argmax function was used to match the peaks of the signals and shift the signal in the appropriate direction to account for start time (both began recording once a threshold of activity had been reached).

![Figure 1: Prototype assembly.](image1)

![Figure 2: Excerpt from Lab Notebook showing experimentation setup](image2)
Results

The two signals were comparable. While the max amplitude varied between sensor, there was consistency in the relative locations of peaks, showing that the ADXL345 (new) could detect and record vibration data at a reliable sampling frequency. While figure 3 shows the apparent overlap of the two signals, figures 4 and 5 show more specific aspect-oriented comparison between the two. Figure 4 suggests causality between the two, and figure 5 models the relationship between the two collected signals.
Discussion

In testing the viability of this more affordable system, it was shown that a Raspberry Pi could be used with an ADXL345 accelerometer to recognize, record and store vibrations made by different events, supporting the hypothesis. This advancement introduces the possibility for more applications: more people would be able to afford this as a life saving device in assisted living homes, it would become cost efficient as a tool for commercial research (such as monitoring foot traffic), and it would become more widely accessible for further research as this product develops in different directions for specialized purposes.

This future specialization should include a development of a secure case for the Raspberry Pi that considers how the case ought to be secured to the structure. This secure attachment leads to a cleaner transfer of the vibrations.

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Notes and References


