The Amtrak: A Look into What can be Improved, and How

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To whom it may concern,

We are a group of students participating in a new experimental class at the University of Illinois Urbana-Champaign called Physics 398: Design like a Physicist. The goal of the course was to find a commonplace issue that we may be able to tackle, design a device capable of taking relevant data, then to present that data to the people able to address it. In our case, we chose to look at the Amtrak, a public transportation method used daily by commuters and tourists alike. For our project, we took the Illini and St.Louis rails from Champaign to Union station in Chicago and back.

One thing that the United States is notorious for is how dated the infrastructure of our transportation systems are. Compared to the EU's high speed trains that go anywhere 130-170 mph, to Japan's Bullet Train, which is always on time and goes up to 200 mph, the U.S. is literally and metaphorically lagging behind. These are not the technical issues we are going after, however. What is surprising, is that while these trains are so much faster, they are smooth enough to have an open cup of tea on, or to write a postcard. What we found from our data runs is that the Amtrak gets extremely bumpy, enough to knock over our (thankfully closed) water bottles, and to have our backpacks slide around on the ground.

What we hope to achieve by contacting you is to get an opportunity to present our findings to possibly influence the State of Illinois into upgrading peripherals on all of the publicly funded trains. We do not expect this presentation to lead to entire trains being replaced or tracks being upheaved. We realize that the speeds of a train are highly dictated by the model used, and that bumps in the track are impractical to fix. However, there is a collaborative Swedish-UI team that argues that certain upgrades like those used in other countries will allow for a much smoother ride, and would allow the trains to generally go faster. We appreciate your time immensely, and hope to hear back. Given the chance to voice our stance, we think we could give a convincing argument as to why it would be very beneficial to the people of Illinois.

Sincerely,

The Amtrackers

The Amtrak

A look into the railways of Illinois

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Abstract:

Statement of Purpose:

The United states is a world leader in many ways. Unfortunately, however, there are many sectors that the U.S. has not improved in decades and seems to have no interest in improving. Compared to other countries, the U.S. is notorious for having terrible transportation infrastructure. For example, the U.S. spends 1.7% (a 20 year low) of its GDP on transportation while China spends 9% and the EU spends 5%. After feeling how rough of a ride the Amtrak was, It was our group's intention to map out a few rides of the Amtrak that ran from Champaign to Chicago, analyze that data, and think of possible qualities to the Amtrak to improve it's ride. We were tasked to "Design Like a Physicist", so while our report will be discussing data and how it can be used to better the lives of Illinoisans, the foremost priority will be our device and thought process.

Instrumentation:

Hardware:

All of the components we had at our disposal as students were provided to us by our professor. Majority of which, were simple Arduino Modules that were bought off of Adafruit. Our base was an Arduino Mega 2600, with an accelerometer, a GPS, and a MicroSD breakout board.These modules were extremely accessible, cheap, and versatile in their capabilities. There were no prevalent shortcomings that were directly caused by the devices themselves. We decided on those modules for very simple reasons. The ADXL326 accelerometer allowed us to take force (after calculation) measurements in 3-axis at up to 35 times a second. The accelerometer was extremely sensitive for our base data taking, reading to two decimal places of acceleration. The Ultimate Breakout GPS acted as a real time clock in UTC and gave us location measurements up to 5 times a second that when plugged into google maps followed the track's path perfectly. The sensitivity of the GPS was down to the decimals of the "seconds" measurement, which means it is able to measure changes in less than 100 feet. The last main component was the MicroSD Breakout Board which allowed us to write data to an SD card as fast as was necessary.

Initially, to learn the coding process and how wiring circuits works, the class began with circuit design via breadboard. It was very basic, with the only added complication being capacitors to prevent burn-out from incorrect wiring. Later, we were provided pre-designed PCBs from our professor to migrate over to. There were some issues, but none that affected our group as it was for the ports of modules we did not use. Our devices were very basic and could be replicated very easily. The PCB was not a necessity, as the breadboard was completely sufficient during our testing runs on the bus.

We were also provided some 3-D printing experience. We were given the opportunity to use TinkerCAD, a free online software, to design cases to make our devices look cleaner and less conspicuous during testing, and most importantly to make travel easier. Once designed, they were printed through machines at the school.

Code and Software:

Data acquisition was done by programming the Arduino Mega 2560 in the Arduino C programming language called to record data from the Adafruit sensors onto a microSD card. The data acquisition starts first by prompting the user through the LCD display to calibrate each axis and using the keypad to proceed per access. The calibration is done by orienting each axis (x,y,z) one at a time to be straight up. This allows the device to then measure what one “G” of force feels like. It then takes the information from the other orientations (e.g. the x is measured during all 3 steps, not just when it is feeling one G) and compares it to the other orientations to get each axis “G reading”. The accelerometer generally reads around 660 ADC counts. After calibration, it generally shows, for our accelerometer, that one G is 20-25 unites from the base of 660. This allowed us to take that number to understand how much of one G is felt at any time and convert it into acceleration.

Initial attempts in the data acquisition to poll the GPS and accelerometer modules revealed that the GPS module had a limited rate on the frequency that readings. As a result, during the operation of the data acquisition the software would suspend activity while waiting for the GPS to receive new data before taking readings from the accelerometer. In order to increase the data points to take between polling, a timer was created that would read from the GPS at a set interval while leaving the Arduino free for other activities. Approximately 6-8 readings from the accelerometer can be done in between each GPS one. After taking all the data each record of data was associated with the GPS coordinates it was taken at through a linear interpolation with the differences between each of these coordinates.

Data Analysis:

How we went about using Origin and QGIS for the histograms/heat maps

All data points have the location they were associated with as GPS latitude and longitude. Quantum Geographical Information System (QGIS) was used to map the data points onto a map of Illinois.

In order to generate an accurate view of the amount of lateral movement that occurs within the train cabins, it was necessary to take a root mean square of the data. To do this, the acceleration values for each direction were squared. These values were then interpolated with the count data as the mean for each 175 count increment (five seconds).

In order to have a more useful independent variable, the longitude and latitude vectors were made into scalars, and converted into miles. These values were then mapped to the root mean square values of the trip, so that they could be viewed in terms of distance along the path of travel.

Finally, the maximum values were interpolated along each 175 count interval and mapped to each interval along with the distance along path of travel. This was done to provide the true magnitude of any rapid changes in movement, despite any rebounds that would occur as a result.

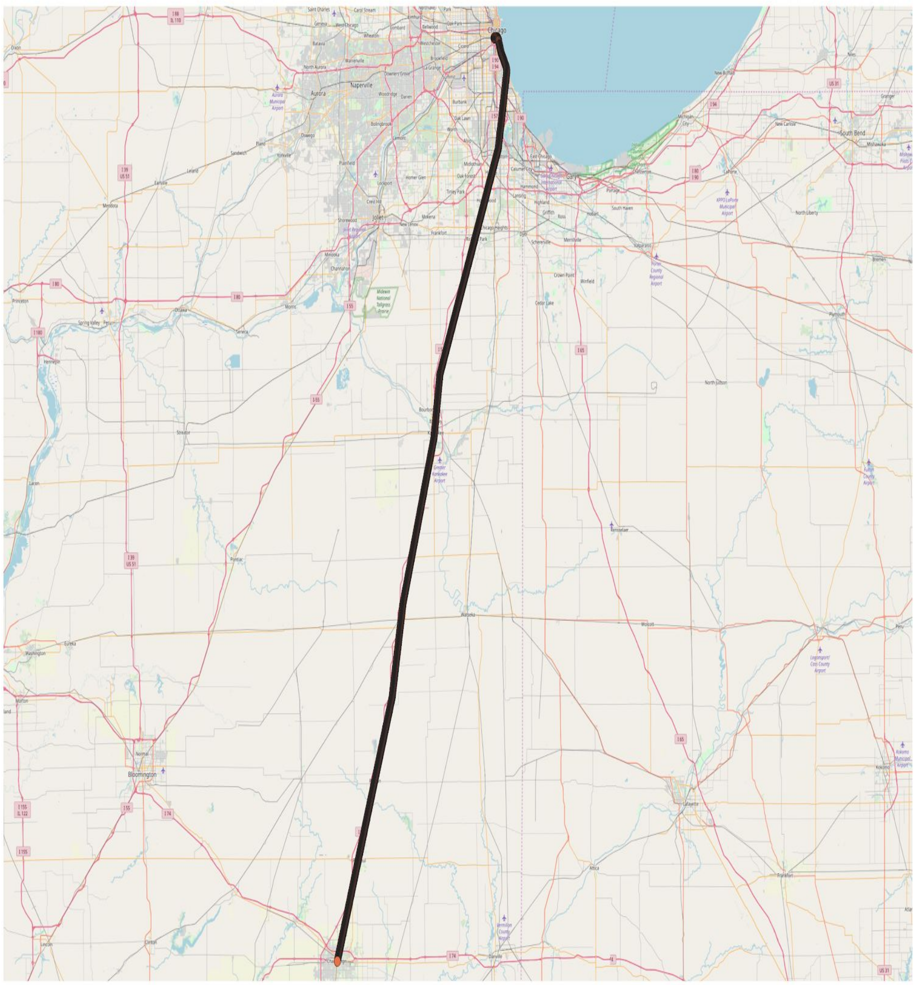


Fig. Readings taken along the trip from Chicago to Urbana-Champaign

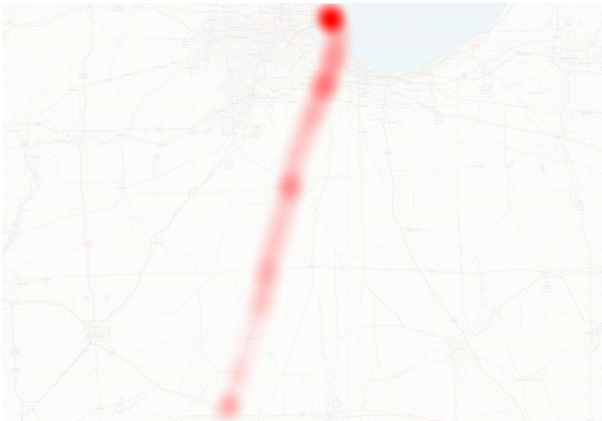


Fig. Heat map of the acceleration across the trip from Chicago to Urbana-Champaign

Testing Process:

The testing process was simple. Roundabout tickets from Champaign to Chicago Union Station and back were purchased, we took the devices on the train, and collected the data. The exact lines taken were the Illini and St. Louis lines. Both of these lines use the GE Genesis P40DC pulling 4 coach cars and 1 business class car. We sat to the furthest back of the cart as we could, placed the device on the floor in front of us, and set the antenna in the overhead. The positive Y direction was set to be forward, so breaking is -Y and acceleration is +Y, +X was set to the right, -X to the left, and Z was up and down. Calibration was done via the code given by Adafruit. Basically it just had us orient each axis' positive direction to be opposite of gravity. It then used each directions feelings of 1 G of force to get accurate readings. The script ran and saved the data to our SD card where it was then used for analysis.

Results:

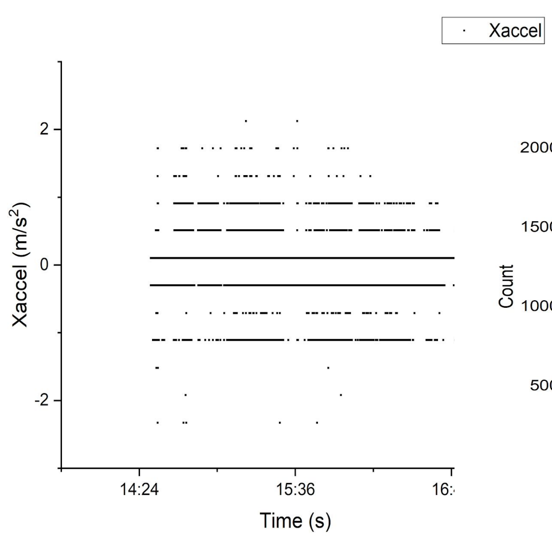
In order to produce graphs for our data, we utilized the program OriginPro. OriginPro accepts the csv file directly from the Arduino, and saves the data into a table, similar to Excel. From here, we set each column to an x, y, or z variable. We then generate plots using the plot function, then specify the boundaries, variables, and type of plot.

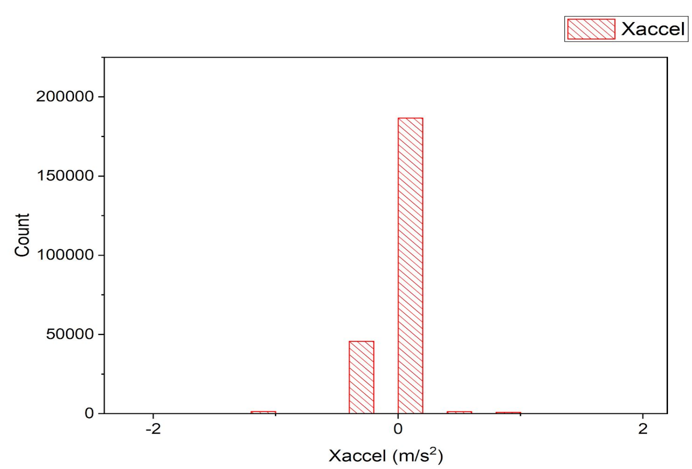
The points used were all the direct readings we recorded, with the exception of the Z acceleration, which was corrected to account for gravitational forces.

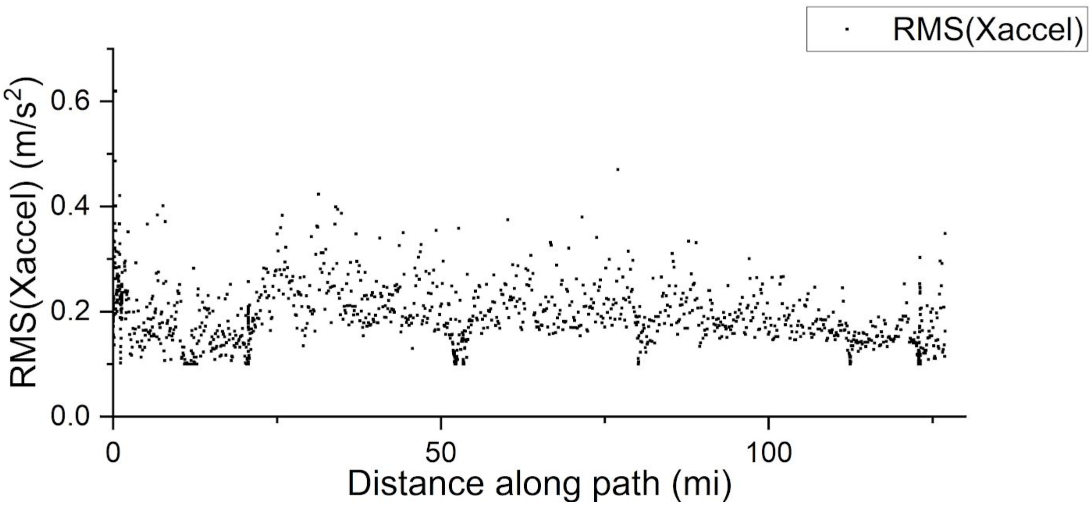
For each direction, we created two plots - one of accelerations vs time, and a histogram that displays the frequency of occurrence.

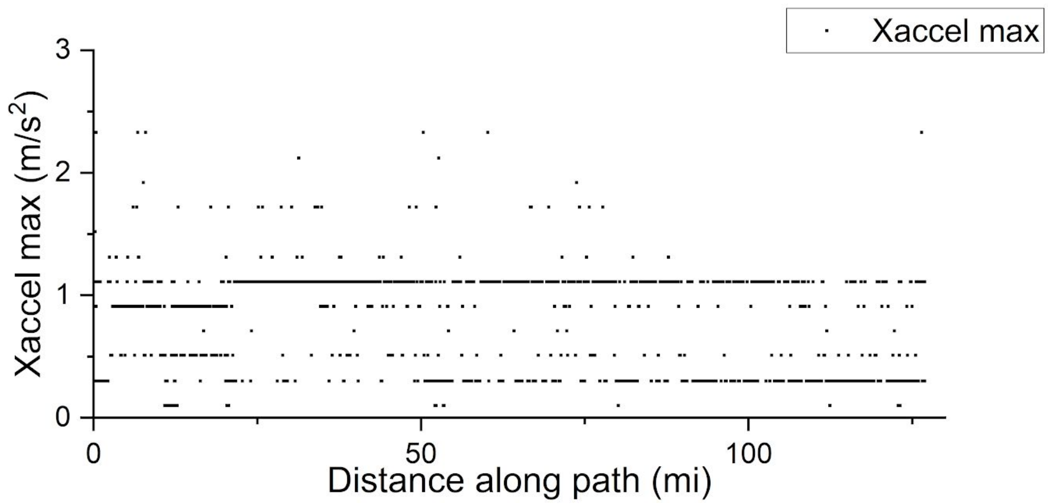
In plotting the acceleration vs time, one can see the sensitivity of the accelerometer, and this was taken into account with the histogram bucket size of 0.20 bucket size.

1. <u>Lateral Movement (X):</u>

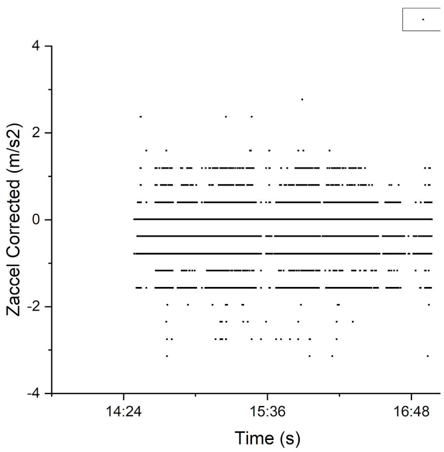


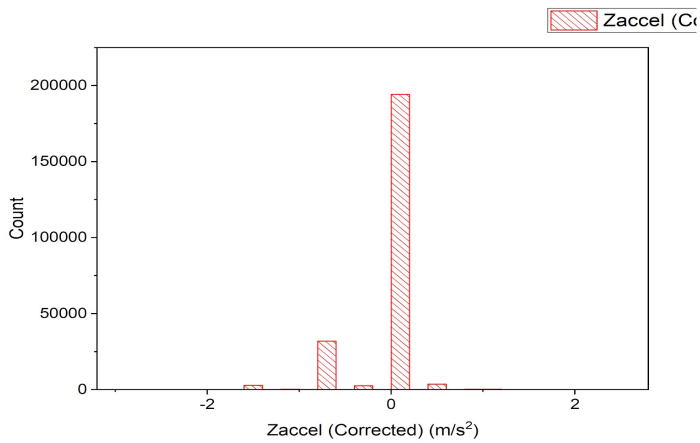


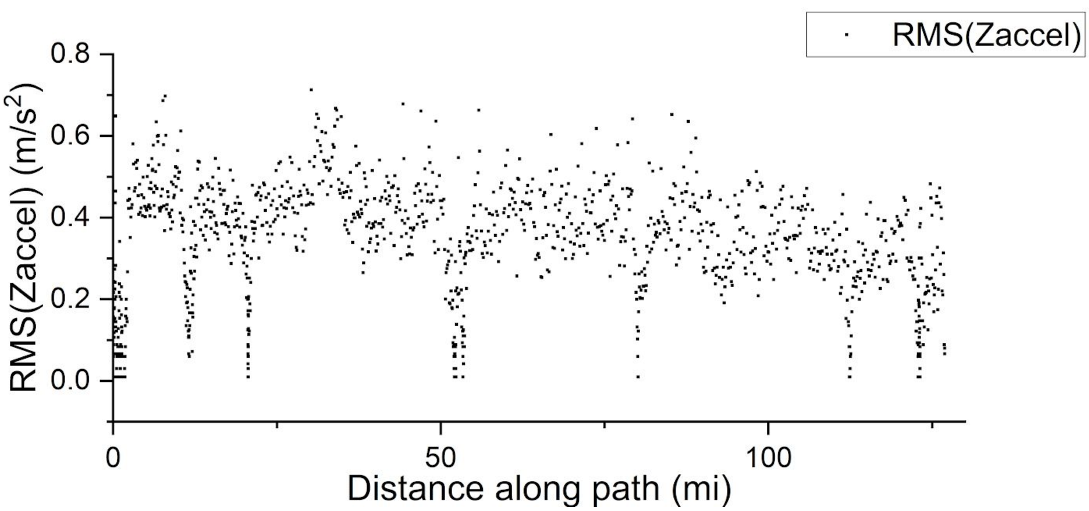

RMS(Xaccel)
RMS(Xaccel) (m/s^2)
0.0
0.2
0.4
0.6
0
50
100
Distance along path (mi)

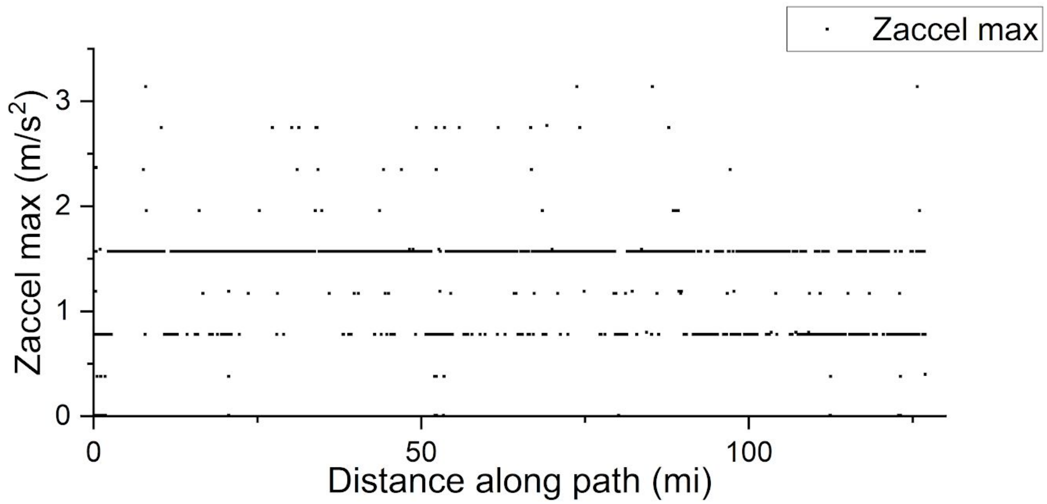

Xaccel max
Xaccel max (m/s^2)
0
1
2
3
0
50
100
Distance along path (mi)

2. Vertical Movement (Z):

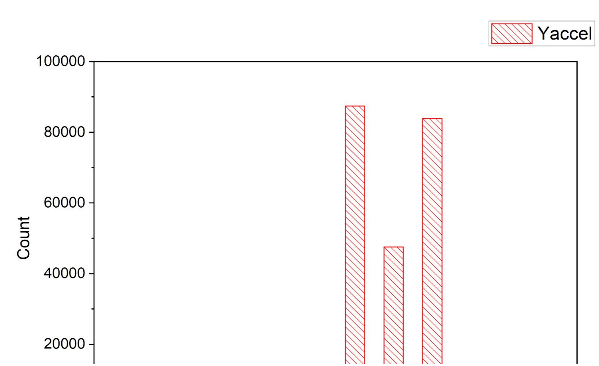


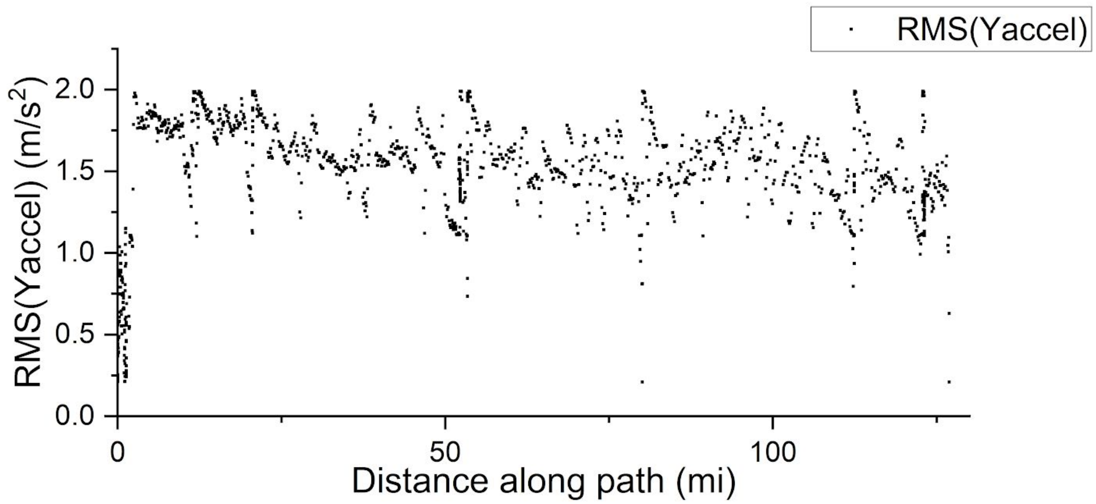


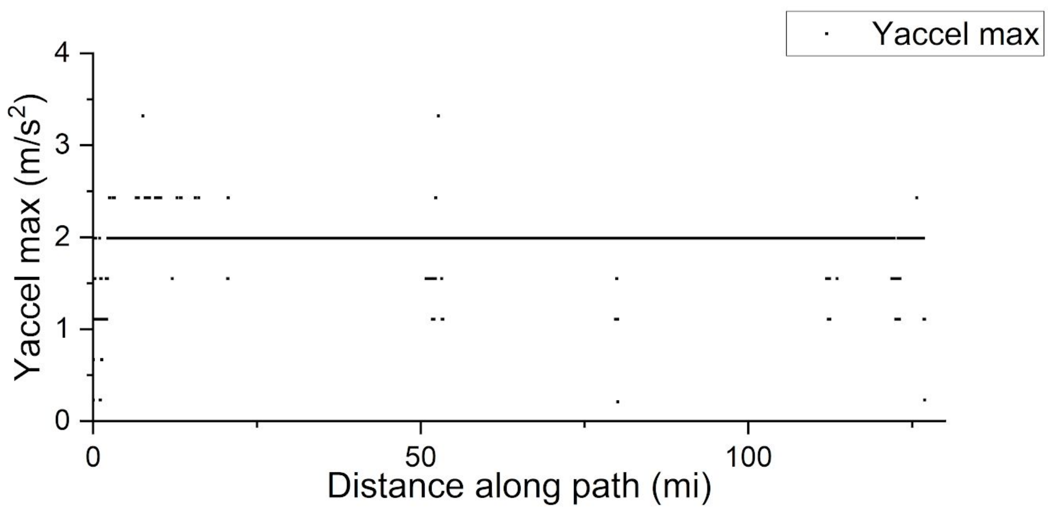




3. Axial Movement (Y):







When viewing each plot for the root mean square accelerations, there are several points at which all three directions experience a rapid jerk. This would likely indicate that there is some significant structural flaw that occurs at these points.

Potential Future Avenues:

Disregarding the issues we ran into with the GPS, and having to deal with time constraints, there are many places this data can be taken. First and foremost, it is extremely valuable for comparison. Whether it be I.D.O.T using it to compare it to rides on buses for pothole tracking, or different states using it as information to compare infrastructure status to infrastructure spending, this data has potential. The most useful idea we can think of, however, is using this same system on trains throughout Europe and Japan. Both the European Union and Japan are heralded for the quality and efficiency of their trains. Getting direct comparison data would allow Illinois to take a look at the worth of improving its citizens commute times and satisfaction. Again, our intention was not to have an entire upheaval of the Illinois train system, but it seems that if used correctly, our data could give insight into potential small changes that would raise the bar in the US. Be it the wheel assemblies themselves, how we treat the metal that is placed for lines, or some other unknown variable, there has to be something to make Illinois' transportation better.

Comparing Infrastructures:

Speaking of potentially comparing rail-line data. Here we hope to just present some sources and information on how the US approaches transportation infrastructure compared to elsewhere in the world. Luckily for us, the European Union provides reports on the state of their transportation systems. Along with that, some journalists have already looked into the differences in our systems. CNN Business took the time to look into the finances of the US compared to other countries and it provided very surprising results (Hargreaves, 2015). Whereas other countries such as China, the U.K. and France spend $12.50, $4.60, and $2.60 per $1,000 of GDP respectively, the United States spends an abysmal 80 cents. The funding that goes into placing high-speed rail lines around the U.S. is non-existent. As the article states "The American Public Transportation Association would like $50 billion over the next six years to fund high-speed rail between certain U. S. cities -- an idea the Obama administration supports but one that has gone nowhere in Congress." (Hargreaves, 2015). Obviously, this article is dated, but it shows the project has gone nowhere. Along with that, a huge difference between the U.S.'s rail lines and other countries is that the U.S. shares lines for freight and passenger. This is a huge potential area for damage to tracks. The weight difference between passenger and freight trains is enormous, so passenger trains are on rails that are under a lot more pressure than necessary. It would be similar to allowing Semi-Trucks to drive through residential areas and then not understanding why the roads were bumpy.. In 2012, 2015, and 2017 the European Union had a data analytics company created something called an RPI report (Duranton, 2017). The RPI, or Railway Performance Index, breaks down what is working and what is not working for European railways. One direct correlation that they have consistently found is that spending = increased performance. “We again found that a railway system’s overall performance typically correlates with the level of public cost, which we define as the sum of public subsidies and investments in the system.”. The report goes into detail of how heavier railway use and stress lead to worse passenger satisfaction. This report will be in the references of this paper and is a highly recommended read. It further shows that the U.S’s lack of spending is causing the bad rides that we experience in Illinois.

Possible Sources of Error (results and discussion):

The issues (which were few in number) that we ran into seemed to be a mixed bag of human and technical error. We successfully got 2 of the 3 PCBs to work, but could not find any direct soldering issues with the 3rd. Overall, the modules themselves worked well, the GPS module needed a separate antenna attachment to actually get connection, but that was no problem. There is always the possibility that the Adafruit modules caused misreadings, as they were cheap and so simple, but there is no reason for us to believe that. Lastly, there is the fact that our main data collection was done from the second floor of the passenger train. There is always the possibility that due to leverage from the increased height that the bumps were exaggerated. However, half of the passengers who ride will be on the second floor, so it isn't like they wouldn't be experienced that anyway.

<u>Summary:</u>

This was a very unique experience that led to use collecting some seemingly useful data. Hopefully in the future this could be done more efficiently without the issues. If we were under less time constraints we could do much more data collection and comparison that would help us eliminate the issues we had. From our experiences riding the trains multiple times, we realized how bad they actually were. None of us had had experiences with the Amtrak prior to the project, and had only heard about it's issues. When compared to a bus or driving yourself, you don't save any time or money, and have a bumpier ride. This makes one wonder why the train would ever be picked over the others in its current state. We weren't able to make any definitive conclusions about what exactly causes the issues with the bumpiness. It may be the wheel assemblies, it may be the way the tracks are laid. What we were able to conclude, however, was that there is a lot of room for improvement in our train system. Any questions about this project can be directed to John Farwick (Johnrf2@illinois.edu).

Sources:

Duranton, S., Audier, A., Hazan, J., Langhorn, M. P., & Gauche, V. (2017, April 18). The 2017 European Railway Performance Index. Retrieved November 29, 2018, from https://www.bcg.com/en-us/publications/2017/transportation-travel-tourism-2017-european-railway-performance-index.aspx

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