Evaluation and verification of dynamic requirements for strollers

Julia Rosengren

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
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MASTER THESIS

Evaluation and verification of dynamic requirements for strollers

Ensuring safe and premium products from Thule

Julia Rosengren

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UNIVERSITY

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Supervisor: Per Kristav
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Abstract

Testing strollers may prevent accidents and breakage, which otherwise could result in severe child injuries. There are standards that suggest procedures for testing strength, durability, safety and more. Thule wants to ensure their strollers are even safer and more durable than the standards suggest to meet their user criteria.

This paper will describe the process of evaluating if the tests Thule subjects their strollers to are comparable with Thule's customers' use of strollers.

In the initial stages, the focus was defining Thule's customers' needs. Following this, accelerations on a stroller called Thule Sleek was measured using accelerometers. The measuring was performed when the stroller was subjected to two outdoor tracks and a standard test called Irregular surface test. The collected data was compared using acceleration- and frequency-graphs. Similarities and dissimilarities amongst acceleration and frequencies on the stroller were discussed.

The results indicated that there was a resemblance between Thule's outdoor tracks, the Irregular surface test and user needs. However, the placement of accelerometers was crucial. When placed on the wheels, the tracks and Irregular surface test differed regarding the overall accelerations on the stroller and what dominant frequencies the stroller was subjected to. When placed on a mass in the stroller seat, the results were predominantly similar.

The outdoor tracks and the Irregular surface test are a useful complement to each other, but don't mirror user needs accurately on their own.

More rigorous testing needs to be done to confirm the result. User needs must be further defined and different analyzing techniques of data must be examined.

Keywords: Accelerometer, stroller, Fast Fourier Transform, Irregular surface test

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But I must thank my mother the most. Through the years, no one has been as patient, creative and supportive as her during my education. Without her I would have given up a long time ago and I wouldn't had made it to the end of this master thesis. She taught me the value of giving myself credit, the benefits of asking the stupid questions and embracing the fact that nothing is perfect. Thank you, mom, and remember that to me you will always be more than

"good enough"

Lund, June 2018

Julia Rosengren

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1 Introduction

1.1 Background

1.1.1 The company

Thule is a Swedish company founded in 1942. Their goal is to make it easier for people to explore the world and their own passions. Their slogan "Bring your life" refers to the company's different products that transports what matters in their customers' lives. They want to be associated with safety, comfort, style and an active life [1]. Thule is mostly known for their cargo carriers, bike racks etcetera, but lately the company has explored new product categories, such as carry-on luggage and strollers [2].

In 2017 Thule reported increased net sales around the world and plans to expand the business even more. The product category *Active with Kids* – which includes strollers, child bike seats and other – has grown fast which has led to increased investments in product development within the category. The market has a high demand for strollers and in the autumn of 2018, Thule will start selling a new stroller named *Thule Sleek* [3].

Since Thule is relatively new to this product category and want to give their customers the quality that defines the company's other products, they want to examine how strollers are reviewed today. By doing so, Thule hopes to be able to deliver the best products and thereby becoming a major player within the stroller product category.

1.1.2 Current standards

Companies may follow guidelines in existing standards for strollers when testing them. The standards Thule is following depends on in which country their products are sold. Standards can have different suggestions regarding the same sort of test, with various levels of difficulty. To be able to score highest on every market, Thule choses to subject their strollers to the hardest conditions provided. According to the supervisor at Thule – Ida Jonsson – the company therefore uses a mix of standards [4]. This paper will focus on the European standard *EN-1888* and Thule's own internal standard.

Still, Thule is not sure the current standards provide a representative image of the company’s users. Therefore, Thule wants to develop a new internal standard with focus on safety and real data that reflects the reality of customers.

1.1.3 **Current market**

There is a large market for strollers today. But many children, around 17 000 per year, have been hurt because of strollers. The injuries can occur when children for example fall out of the stroller or get strangled by straps. With users demanding higher safety, the market has had to follow which has led to fewer child injuries related to stroller use [5]. Many companies subject their strollers to certified tests to be able to be attractive on the market [6], and the competition is therefore great. Being at the forefront of development can therefore promote Thule, and perhaps lead to fewer child injuries.

1.2 Master thesis

1.2.1 **Purpose**

The intention of this master thesis is to help Thule become a great contributor to the market of strollers today. The purpose is to critically review a current standard test – Irregular surface test (IrregularST) – and compare it to Thule’s test tracks – Track 1 and 2 – with the help of accelerometers. Later, eventual improvements will be discussed. The end goal is to see if Track 1, 2 and IrregularST are comparable regarding impact on the stroller, and to see if they represent what a stroller is exposed to by its users.

1.2.2 **Delimitations**

Thule has many strollers on the market with more to come, but in this master thesis only Thule Sleek will be tested. There are also many various tests in standards which could be examined. This paper will only focus on IrregularST.

Why these delimitations, and others, were made will be revealed gradually during this report.

1.3 Process

Below is a description of how the project and report is structured.

The process was iterative with many parallel projects going on at the same time. The main structure was as Figure 1 shows. It demonstrates that previous parts were revisited continuously during the project.

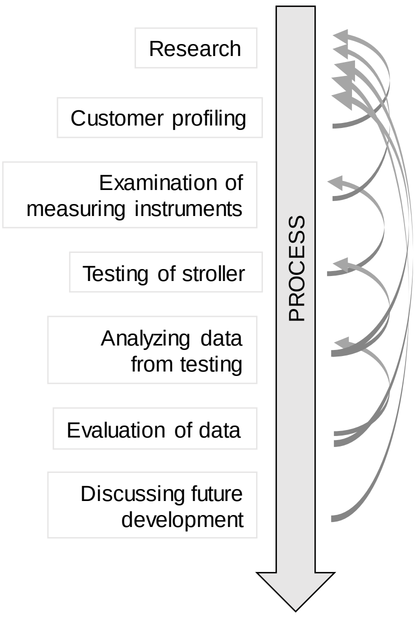


Figure 1 - The iterative process of this master thesis

The report will be in a chronological order. The headlines sometimes have sub-purpose, -method, -result and -conclusion. This is because the project consisted of many parts which build upon one another. A chronological report was therefore considered relevant to increase readability.

2 Customer profiling

This chapter will describe how relevant data and information were collected from users and how those users were chosen.

2.1 Purpose

Thule wants to make strollers for a typical Thule user, and give their customers the quality stroller they search for. It's important to find an accurate Thule customer profile because if users don't subject their strollers to a high amount of stress, Thule won't have to subdue their strollers to the hardest tests. If the users use their strollers in very demanding situations, perhaps Thule must test their strollers more. A too high-quality stroller will cost Thule money and time during developing and testing, and some of the customers will pay for more than they need or want. If the strollers underperform in tougher environments, Thule loses its high-quality reputation. In both scenarios, Thule risks losing customers to other manufacturers. Because of this, and since there is no complete preexisting user data, it is necessary to start the project with a basic customer profiling.

2.2 Difficulties

2.2.1 **Grounds**

When defining a customer profile, it's important to look at what kind of different grounds the stroller rolls over. Later during testing, the conditions should be as easy as possible to recreate. Therefore, defining different grounds is a challenge. For example: asphalt can be smooth or rough and potholes can be of different diameters and depth. Testing the stroller when rolling over these grounds and obstacles is therefore no exact science.

2.2.2 **Customers**

Since Thule is relatively new to the stroller market, they have not fully defined their customers yet. On a normal curve of potential customers, as seen in Figure 2, Thule prefers to make strollers for customers somewhere on the right. This is because the company stands for quality and doesn't mind being a bit overqualified for some customers [7]. It's still a broad span and an informed suggestion of where the aim should be on the normal curve will be examined.

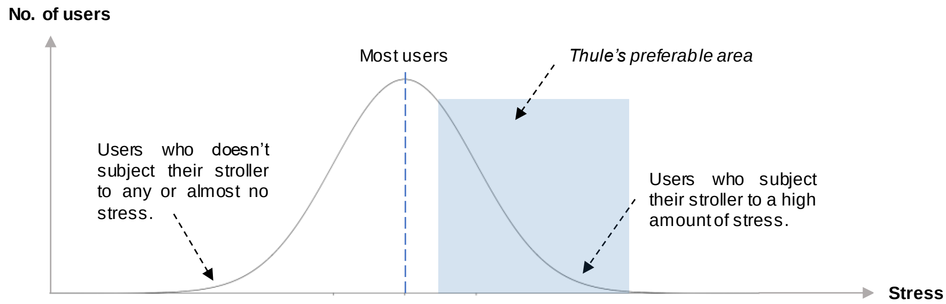


Figure 2 – Standardized normal curve for stroller users, described by Thule. (Note that this is not a real description of users, only a visual guide).

2.3 Pilot testing

2.3.1 **Purpose**

A pilot test is a trial test. It is used to see if questions and instructions are formulated in an understandable and relevant way. According to Arvola [8, p. 134] a pilot test can help find mistakes and errors in time before performing the test with an actual user. In this way, time, money and effort can be saved in case of a faulty test which generates inadequate or inconclusive information.

2.3.2 **First test**

2.3.2.1 Method

The first pilot test took place with a mother, living in Arild, Sweden. She was chosen because of her active lifestyle and the challenging terrain of Arild's surroundings. This seemed to fit an eventual Thule customer profile. She didn't own a Thule stroller, but still had a stroller adapted to more challenging terrain. The test, which can be found in Appendix A, was performed using a protocol developed according to Arvola's information about contextual analysis and user mapping [8, pp. 45, 51]. It combines observations with interviews to get a deeper understanding of events and a user's habits. Firstly, the observation took place. The test participant took her youngest child on a walk with a stroller and different obstacles – for example the number of curbs the stroller rolled over and different grounds – were noted. The walk was later marked on a website where joggers go to register their route to see how long they have run [9]. With this website, the length of different terrain was estimated. An example of how a marked map can look is found in Figure 3.

Figure 3 - An example of how a marked stroller route looks on the website (Lund, Sweden)

Afterwards an interview was held to get a deeper understanding of her experiences with her stroller. The data from the observation was then interpreted and translated to comparable numbers.

2.3.2.2 Result

The interview clarified that the test participant thought her stroller was fine, but believed it was a bit unsafe since it was prone to fall over. It had recently gotten a flat tire which she had switched to another smaller wheel so the stroller wasn't completely leveled.

The observation result from the first pilot test can be found in Table 1.

Table 1 - Terrain and obstacles during the first pilot test in Arild

Ground	***Length (m)***	***Length (%)***	***Events/Obstacles***	***Frequency (no)***	***Frequency (%)***
Asphalt	1468	76.50	Curbstone	6	0.31
Gravel	279	14.54	Stairs	106	5.52
Grass	2	0.10	Bumps	8	0.42
Soil	0	0	Pit	0	0
Sand	0	0	Bump with object	2	0.10
Snow/Ice	0	0	Child bounces	0	0
Paving stone	0	0	Child stands wrongly	1	0.05
Stone tiles	0	0	Other***	11	0.57
Wood deck	0	0			
Woodland*	71	3.70			
Other**	99	5.16			
Total	**1919**	**100**			

*def. as grass, soil, stones etc.

***2 thresholds, 5 child climbs in, 4 child climbs out

**6 m coarse gravel and 93 m stairs

Most of the terrain was asphalt, though it was covered in small gravel, as seen in Figure 4. The figure also gives an example of the slopes that Arild mostly consist of.

Figure 4 - Asphalt slope with small gravel on top

2.3.2.3 Conclusion and discussion

The interview could be shortened since some of the information obtained was not relevant for the evaluation of dynamic or static loads on a stroller. The reason so many questions were on the test to begin with is that before starting it was difficult to know what knowledge was needed. The idea was to start the project wide and gradually narrow down the parameters. The goal was to always ask for the worst terrain and obstacles the stroller has been subjected to, since Thule wants to prepare for harder conditions than the average user needs. The observations could be even more specific and have categories added.

This way of testing was time consuming since the child often wanted to stop and play along the way. Planning the observation to a date when the mother, the child and the observer where available took a lot of logistic planning. Developing a new way of testing effectively was a suitable way to continue. A second pilot test should be performed to evaluate the newer test.

2.3.3 **Second test**

2.3.3.1 Method

A mother from Trä, Sweden was the second person to join the pilot testing. She tried mapping the stroller route herself. In this way, the route could be examined later without the mother or child involved, thus saving time and planning. From the obstacles-list all the “events” were taken out since only the terrain was being investigated this time. The test form, in Appendix B, was emailed to her and she managed to navigate the test and answer the questions the way it was intended. To get extra feedback, the test was also sent to the first test person who also understood the new layout. Later the newer route in Trä was inspected and different terrain and obstacles were noted. To make the mapping more accurate, a printed map of the stroller route was brought. Every change of terrain could easily be marked in the map and later be measured on the designated website.

2.3.3.2 Result

In the form the test participant wrote that the reason for purchasing her stroller was that it should be able to handle more difficult terrain. The stroller brand was coincidentally the same as in the first pilot test. It felt safe and the only problem was a flat tire, which also happened to the stroller in Arild.

The observation differed from the first pilot test and can be found in Table 2.

Table 2 - Terrain and obstacles during second pilot test in Trä

Ground	***Length (m)***	***Length (%)***	***Events/Obstacles***	***Frequency (no)***	***Frequency (%)***
Asphalt	220	11.64	Curbstone	0	0
Small gravel	1380	73.02	Threshold	0	0
Coarse gravel	0	0	Bumps	0	0
Grass	0	0	Pothole	74	3.92
Soil	0	0			
Sand	0	0			
Snow/Ice	0	0			
Paving stone	0	0			
Stone tiles	0	0			
Wood deck	0	0			
Woodland*	290	15.34			
Stairs	0	0			
Total	**1890**	**100**			

*def. as grass, soil, stones etc.

There was less variety of grounds and obstacles than in Arild. The terrain was mostly gravel road and woodland, as seen in Figure 5. The gravel in the picture was estimated to be small.

Figure 5 - Gravel road (small) on the left, woodland on the right

2.3.3.3 Conclusion and discussion

Without the parents or the child, the walk wasn't as time consuming, and it was easier being observant to obstacles on the road. A problem with the website used for mapping is that it doesn't show the length of slopes, only the length from a bird's view. The second pilot test felt significally shorter than the first one (taking the time difference into account). In Arild there were mostly slopes and hills which means that route was longer than it seemed on the website. Even with this miscalculation, this way of measuring seems to work quite well. The test should be able to be sent out to the other test participants.

2.4 Main testing

2.4.1 **Finding suitable users**

When deciding which users who were to be included in testing, a user description needed to be created. Firstly, to get a deeper understanding of how users and their use are described, a document with keywords was made. The keywords came from Thule's own *Product Guide – Active with Kids* from 2017. Words that stood out and were repeated multiple times can be found below.

- Active life
- Active parent
- Multisport
- Safety
- Comfort
- Innovation
- Explore
- Active
- Durability
- Long life span
- Flexible
- Easy to use
- High performance
- Simple to bring

From the list a customer personality took form. It looked like Thule wants their customers to be outside a lot, going to new places and use high quality gear. This could be applied to the two people already interviewed, both living in the countryside. To make sure this was a correct interpretation, more information was needed. A meeting took place with Thule employees, focused on user experience and design, to get a clearer understanding of what kind of people to look for. The conclusion was that Thule did not have a clear answer themselves of which customers to include since their previous customers have been described as active, sporty and out in more difficult terrain, while Thule's newer customers will be found in the cities, not using their strollers in as extreme conditions [10]. To cover as many of Thule's customers as possible, two different testing forms where made. One for urban users in the city, and one for more active users living in the countryside.

2.4.2 Urban users

To get in touch with urban users, Facebook groups and personal contacts were used. Malmö was chosen in the urban category since it's Sweden's third largest city [11] and therefore should be a representative candidate of cities. It also required a short traveling distance, thereby saving time and money. The test form sent out is found in Appendix C.

2.4.2.1 First result

In the interview form it said no stairs were used inside since the home building had an elevator. The reason for purchasing the stroller (which wasn't from Thule) was that it was flexible and easy to bring. The only damage was to a splash guard that had gotten stuck in a bus door.

There were mostly paving stone and stone tiles with different variations, as seen in Table 3.

Table 3 - Terrain and obstacles during first urban test in Malmö

Ground	*Length (m)*	*Length (%)*	*Events/Obstacles*	*Frequency (no)*	*Frequency (%)*
Asphalt	5	0.54	Curbstone	6	0.64
Small gravel	0	0	Threshold	2	0.21
Coarse gravel	0	0	Stairs	0	0
Grass	0	0	Bumps	1	0.11
Soil	0	0	Pothole	0	0
Sand	0	0	Other**	3	0.32
Snow/Ice	0	0			
Paving stone	367	39.38			
Stone tiles	560	60.09			
Wood deck	0	0			
Woodland*	0	0			
Stairs	0	0			
Total	**932**	**100**			

*def. as grass, soil, stones etc. **Tiles with pattern for blind people

The stone tiles varied in size and shape. In a few places there was added orientation pattern for the visually impaired as seen in Figure 6.

Figure 6 - Paving stone on the left, stone tiles with orientation pattern on the right

2.4.2.2 Second result

The ground was mostly small gravel and stone tiles. The most frequent obstacle was curbstone, as seen in Table 4.

Table 4 - Terrain and obstacles during second urban test in Malmö

Ground	***Length (m)***	***Length (%)***	***Events/Obstacles***	***Frequency (no)***	***Frequency (%)***
Asphalt	217	7.12	Curbstone	10	0.33
Small gravel	1521	49.93	Threshold	2	0.07
Coarse gravel	0	0	Stairs	0	0
Grass	0	0	Bumps	0	0
Soil	0	0	Pothole	1	0.03
Sand	0	0			
Snow/Ice	0	0			
Paving stone	29	0.95			
Stone tiles	1279	41.99			
Wood deck	0	0			
Woodland*	0	0			
Stairs	0	0			
Total	**3046**	**100**			

*def. as grass, soil, stones etc.

The form said an elevator was accessible in the home building which lead to no stairs being used. The reason for buying the stroller (which wasn't from Thule) was that it looked good and had good testing results. (These tests were not disclosed). The dad said the only time the stroller felt unsafe was when they changed the baby's position while it was in the stroller.

2.4.2.3 Summary and discussion of urban users

During the project it became clear that gathering information about users, especially urban users, wasn't the highest priority right now. To get a better understanding of user behavior, a lot more tests would have to be compiled and not enough time would be given during this master thesis. Therefore, only two urban users were examined. The conclusion from those two was that they mostly use their stroller on stone tiles, with small gravel as a close second which can be seen in Table 5. Curbstones were the most occurring obstacle, but they only covered 0.4 % of the route. Interestingly, none of the users used stairs during the routes since both had access to elevators. The result would probably be different if more users were tested and if other cities were explored.

Table 5 – Summary of grounds and obstacles, urban users

Ground	***Length (%)***	***Obstacles***	***Frequency (%)***
Asphalt	5.58	Curbstone	0.40
Small gravel	38.24	Threshold	0.10
Paving stone	9.95	Bumps	0.03
Stone tiles	46.23	Pothole	0.03
		Other*	0.08
Total	**100**		

*Tiles with pattern for blind people

2.4.3 **Countryside users**

Since the two pilot tests had provided sufficient data, those users were included in the countryside category. To get in touch with this user category, personal contacts were used.

2.4.3.1 Third result

This route had many kinds of grounds. A part of the route was completely flooded and was estimated to be woodland. In another part the gravel had washed away. This was estimated to be gravel road. Some of these grounds can be found in Figure 7.

Figure 7 - Flooded woods on the left, muddy (previously gravel) road on the right

Another part of the route was gravel road with sand blown in from the beach. It was estimated to be sand. Some parts were easier to categorize such as grass, seen in Figure 8.

Figure 8 - Grass on the left, gravel road with sand on the right

Small gravel was the most common ground, as seen in Table 6.

Table 6 - Terrain and obstacles during countryside user test in Bjärred

Ground	***Length (m)***	***Length (%)***	***Events/Obstacles***	***Frequency (no)***	***Frequency (%)***
Asphalt	1598	26.93	Curbstone	2	0.03
Small gravel	2637	44.43	Threshold	2	0.03
Coarse gravel	0	0	Stairs	0	0
Grass	854	14.39	Bumps	10	0.17
Soil	489	8.24	Pothole	29	0.49
Sand	173	2.91			
Snow/Ice	0	0			
Paving stone	0	0			
Stone tiles	0	0			
Wood deck	0	0			
Woodland*	184	3.10			
Stairs	0	0			
Total	**5935**	**100**			

*def. as grass, soil, stones etc.

The most occuring obstacle was potholes, seen in Figure 9.

Figure 9 - An example of potholes in gravel road

Overall, the owner hadn't experienced any problems with the stroller (which wasn't from Thule) according to the test form.

2.4.3.2 Summary and discussion of countryside users

Only three users were examined which is much less than needed when trying to make a reliable user profile. But as mentioned in the summary about urban users, there wasn't enough time during the master thesis to provide sufficient data for a complete user profile. The profiles could still be compared to future measured data to see if there is some correlation with real users.

Countryside users mostly walked on small gravel and asphalt with potholes and stairs as the most frequent obstacles, which is seen in Table 7. Compared to the summary of urban users, which only consisted of 5.58 % asphalt and no stairs occurred, this seems a bit surprising since one might guess that asphalt and stairs would mostly be found in the cities. The numbers would probably be more representative with more user data, to better match the reality.

Table 7 - Summary of grounds and obstacles, countryside users

Ground	***Length (%)***	***Obstacles***	***Frequency (%)***
Asphalt	33.72	Curbstone	0.08
Small gravel	44.09	Threshold	0.04
Coarse gravel	0.06	Stairs	1
Grass	8.78	Bumps	0.18
Soil	5.02	Pothole	1.06
Sand	1.78		
Woodland*	5.59		
Stairs	0.95		
Total	**100**		

*def. as grass, soil, stones etc.

Figure 9 shows different kind of potholes which indicates the difficulty of defining obstacles. Obstacles vary in nature and therefore, mapping obstacles was subjective and these will perhaps be more clearly defined in eventual future testing.

2.5 Conclusion

It won't be decided where Thule should be on the normal curve in Figure 2 since not enough data has been collected to make a relevant data base. The most important thing obtained during customer profiling was the method to map the different grounds of a route. This method will be used later when mapping Thule's own stroller routes – Track 1 and 2. The gathered user profiles could be compared to those results to find similarities or dissimilarities.

3 Use of accelerometer

This chapter will describe the equipment and program used when collecting data from stroller routes. It will also mention basic knowledge needed to collect and handle data.

3.1 Purpose

Ground data collected from customer profiles should be translated into loads which occur on a stroller when rolling over those grounds. This is a way to describe how the stroller reacts when being subjected to alternate loads. These loads can be described as movement, or acceleration, in various directions. This data could be a tool to compare Track 1 and 2 with IrregularST. The movement of the stroller must be translated into acceleration and that is what accelerometers are for.

3.2 Sensors

The sensors, also called accelerometers, used by Thule are PCB Piezotronics TLB 333B30. They can measure the acceleration in one direction [12] which requires the use of multiple accelerometers placed differently when measuring in many directions at the same time. The acceleration is measured in the unit $g = 9.81\ \mathrm{m}/s^2$. An accelerometer is found in Figure 10.

Figure 10 - The accelerometer Thule uses for measuring acceleration in one direction. The arrow is showing in which direction acceleration is measured. (Retrieved June 7, 2018, from http://www.pcb.com/products.aspx?m=tlb333b30).

The directions are defined as the X-, Y- and Z-axis which will be clarified later in this chapter. Six accelerometers were provided which means acceleration could be measured triaxially in two measure points, biaxially in three measure points etcetera, at the same time.

The data retrieved during testing with sensors are saved and processed by a portable Siemens device called LMS SCADAS XS. A tablet is used to view the acquired data both during and after testing [13].

3.3 Mounting sensors

To be able to install the sensors and navigate the interface of the complementary technology, without risking compromising the retrieved data, all had to be examined and tested first.

It was of utmost importance that the sensors were placed with precision according to Thule's predefined directions, so that the data would be trustworthy and comparable. Those directions can be found in Figure 11.

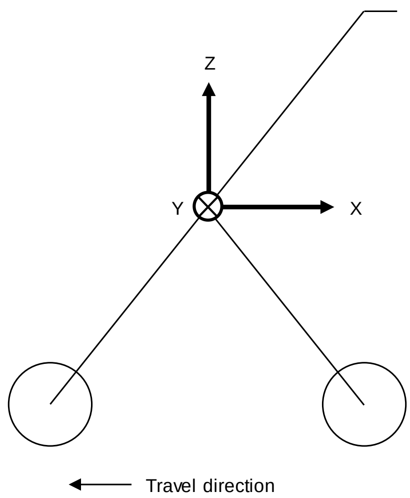


Figure 11 - Thule's predefined directions on stroller. (Note that the sensors can be attached anywhere, not only in the middle).

To ensure the accelerometers were placed correctly, and aligned with the respective axis, an epoxy clay – LOCTITE EA 3463 – was used to sculpt leveled platforms on the stroller. The clay hardens slowly during use but becomes very stiff when solidified [14]. Before it dried, a small metal block was attached using double-sided tape. This can be seen in Figure 12.

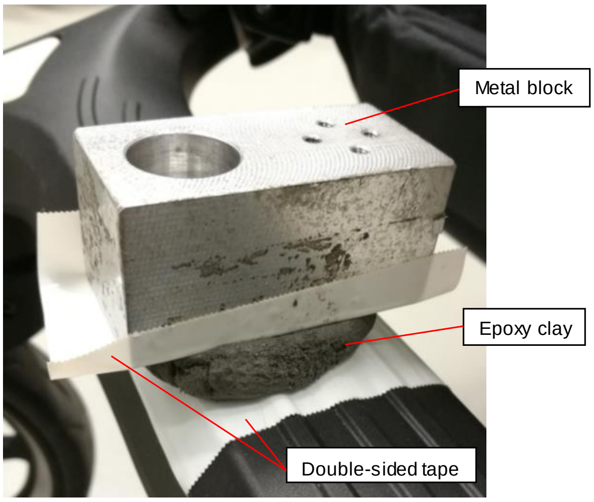


Figure 12 – The leveled base for the sensors to be fastened upon

The sensors could be attached on top of the block when the clay had hardened, again using double-sided tape.

An example of how it looks when measuring triaxially in one point can be found in Figure 13.

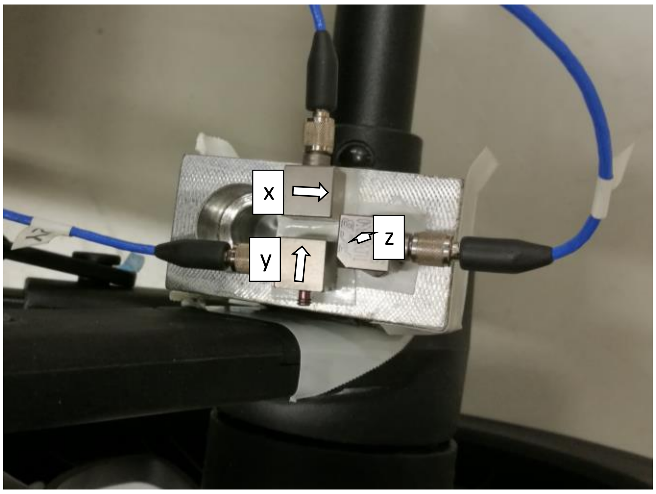


Figure 13 - Triaxial placement of accelerometers

3.4 Interpretation and filtering of data

When looking at acceleration data collected from the sensors, large peaks at some points in time may occur. It could be interpreted as if the stroller is suddenly subjected to immense force that would mean it has been hugely displaced. This might not be the case. If a large peak occurs it could have a high frequency, but during a short period of time. This doesn't have to be damaging to the stroller. A lower frequency during a longer period of time could be more damaging since the stroller could have been massively displaced. In Figure 14 there is a visual representation of this.

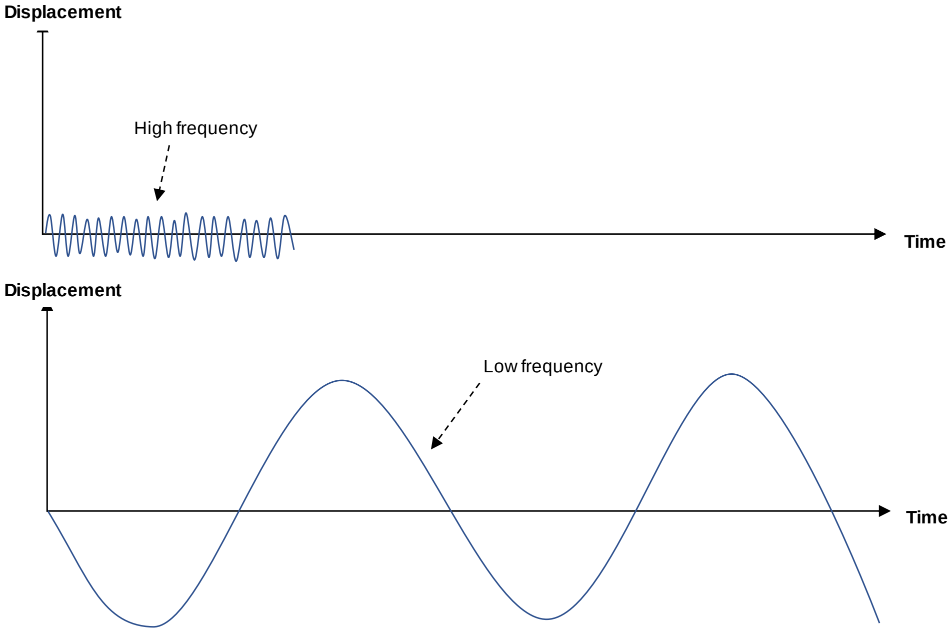


Figure 14 - A visual representation of how a low frequency can affect an object more than a higher frequency.

Filtering data is a way to get rid of frequencies that are not interesting regarding damage to an object. In the car industry for example, only frequencies between 0.5-50 Hz are included after filtering. According to Mårten Elliot at Thule, higher frequencies than 50 Hz has been proven not interesting to include since those don't contribute to any damage on the vehicle. Same goes for the frequencies lower than 0.5 Hz [15]. It's impossible to know from the beginning exactly which frequencies are damaging and several years of testing has narrowed the frequency span to 0.5-50 Hz. According to Ida Jonsson, no knowable similar research or testing exists for strollers today, which is why testing will be necessary when filtering [16].

4 Critical measurement points

This chapter will describe how measurement points on the stroller were decided and which they are.

4.1 Purpose

When measuring acceleration on strollers it is important to place the accelerometers on interesting points on the stroller to get relevant data. Interesting points can be where the acceleration is high or at places where there are limitations to how high the acceleration can be. But it is not obvious where those points are since different strollers have different designs and therefore different points of interest. If Thule wants to add a method with accelerometers to their internal standard it is important to make the test repeatable.

4.2 Research

To get deeper understanding of the subject, Patrik Spånglund at RISE – *Research Institutes of Sweden* – was contacted to answer questions about their testing of strollers. He himself had been working at RISE with standards like *EN-1888* for 12 years. He said that RISE doesn't test with accelerometers on strollers at all. The only place he though was relevant to measure on was the mass in the stroller seat, which represents the child, in all directions. The child's comfort could thereby be measured [17].

Another person at RISE, Gunnar Kjell, suggested having accelerometers as close to the ground as possible so that data wouldn't be misrepresented by the stroller body. His reason was that if the stroller would be mounted on a vibrating table, the vibrations of the table must correspond to the vibrations of the stroller. If the accelerometers were placed higher in the stroller body, the stroller's own dampening would distort the frequencies [18]. By placing the sensors lower, the frequencies tested could be determined to be the frequencies the stroller is subjected to. A vibrating table is a tool used by Thule and others today to test for example cargo carriers by subjecting them to frequencies that represent the use of customers. This way of testing allows personnel to program the table to vibrate in a certain pattern for a defined period of time, mount the test object on top and then be able to test the product in the same way repeatedly. This makes sure that personnel don't have to drive the car with the product themselves for a long period of time repeatedly, without the ability to do it the exact same way every time [7].

Further research showed that too vigorous shaking (Frequency: 2.5-3 Hz, Amplitude: 50 mm) of a child during a few seconds could lead to severe brain damage [19] which made it a matter of safety for the child to test the mass representing the child.

Other points were more difficult to determine since no stroller is designed in the same way. It would be challenging to make a repeatable test if following Thule's initial recommendation which was measuring on the front- and back-wheel axis beyond the child test mass. Not every stroller has both a front- and back-wheel axis which can be seen amongst Thule's own strollers in Figure 15.

Figure 15 – Thule Sleek on the left (front axis), Thule Glide 2 on the right (no front axis)

According to the supervisor at the company, Ida Jonsson, it was not necessary to make the test repeatable to get the information needed. She said only Thule Sleek would be measured for now. Firstly, it would be tested outside in a real environment on Thule's test routes – Track 1 and 2 – which were added to their internal standard in the end of March 2018. Later it would be subjected to IrregularST, to make it possible to draw conclusions about the credibility of the existing standard test [20].

According to Mårten Elliot at Thule, it was important to measure in points which gave an idea of how the stroller moved during tests, both regarding rotation and translation. According to him the mass wasn't the most interesting measure point regarding stroller movement. To be able to measure this, the sensors would have to be placed in such a way so they would create a plane and cover directions which gave information about the stroller body's movement. This placement could possibly be used later on Thule’s vibrating table. A suggestion of the placement, seen in Figure 16, was given by Mårten.

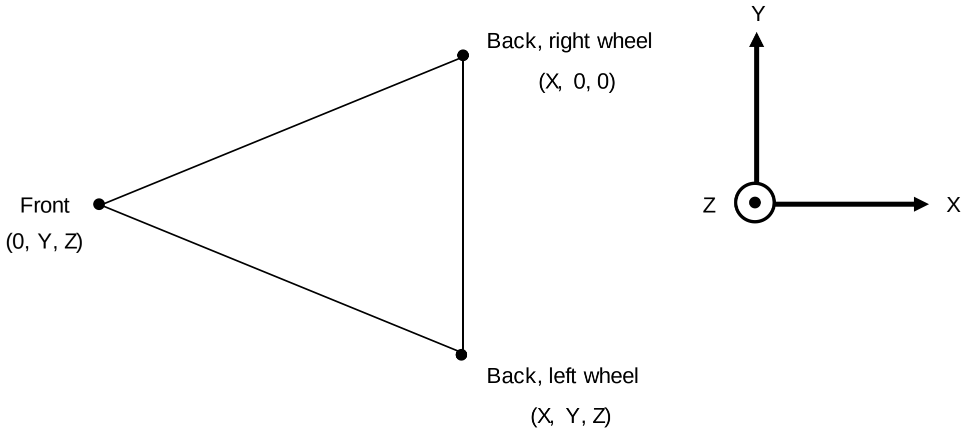


Figure 16 - Stroller plane and which directions to measure, seen from above.

In this configuration, rotation around every axis and translation in every direction could be measured [15]. The back-left wheel acts as a reference point. Only five accelerometers would have to be used, and the extra could be placed at the front in the y-direction. The hypothesis was, since the front wheels where movable sideways, a lot of movement would occur there.

4.3 Testing sensors

Measuring in the configuration as seen in Figure 16 and on the mass, would take two different sensor arrangements since it wasn’t possible to measure in all points at once. That would require nine sensors and only six were provided. A problem when changing the configuration could be that, if the stroller has large variations each time it’s maneuvered, the data could be compromised. To check if it was at all possible to get similar results at different times while walking with the stroller, a minor test was computed. The stroller was rolled on grass, asphalt with gravel on top and up and down curbstones several times to test the configuration. It seemed that the sensors gave similar results each time which indicated that it would be possible to measure in different configurations at different times and still get reliable, semi-repeatable data.

4.4 Conclusion

The configuration in Figure 16 will be used. When measuring on the mass, only the center of the mass will triaxially be measured. A summary of how the sensors should be placed during testing with Thule Sleek is seen in Table 8.

Table 8 - Summary of sensor configurations

		Configuration 1 (front axis, back wheels)				
Sensor No.	1	2	3	4	5	6
Placement of sensor	Right back wheel	Front, middle	Front, middle	Left back wheel	Left back wheel	Left back wheel
Direction	*x*	*y*	*z*	*x*	*y*	*z*
		Configuration 2 (mass)				
Sensor No.	1	2	3			
Placement of sensor	Mass center	Mass center	Mass center	-	-	-
Direction	*x*	*y*	*z*			

5 Testing of stroller

5.1 Thule Sleek

Thule Sleek is a four-wheeled stroller intended to be used by active parents in the city. It’s versatile with many add-ons such as a bassinet or a sibling seat. These can be mounted facing the parent or facing forward [21]. In Figure 17 these examples are found. During testing, the left version will be used.

Figure 17 - Thule Sleek. The arrangement on the left will be measured.

5.2 Compared tests

Throughout testing, the requirements from Thule’s newer own standard – 20103 Driving test of stroller – and the IrregularST, were followed. During all testing the stroller was loaded with its maximum weight which was a metal weight of 22 kg in the seat representing the child, and a 5 kg bag in the cargo space below the seat. The handle bar was in its most extended position and the seat in upright position.

5.2.1 20103 Driving test of stroller

The stroller was subjected to Track 1 and 2 in Hillerstorp, Sweden, with each track providing different challenges for the stroller such as stairs, curbstone and woodland. The walking speed should be 5 km/h. The requirements for passing this test were that the stroller was fully functional after both tracks and that safety regarding the stroller wasn't compromised.

5.2.2 Irregular surface test

This is one of the standard test the stroller should be subjected to according to *EN-1888.* The stroller is mounted on a treadmill with two different kinds of obstacles defined in the standard, see Figure 18. The speed should be (5 ± 0.1) km/h and must pass over the configuration, seen in Figure 19, 72 000 times [22, pp. 27-28, 55-56]. The requirement for passing this test was that no breakage or deformation were allowed if it impaired the safety of the stroller. Observe that this test doesn't demand the stroller to be fully functional after the test as for the *20103 Driving test of stroller.*

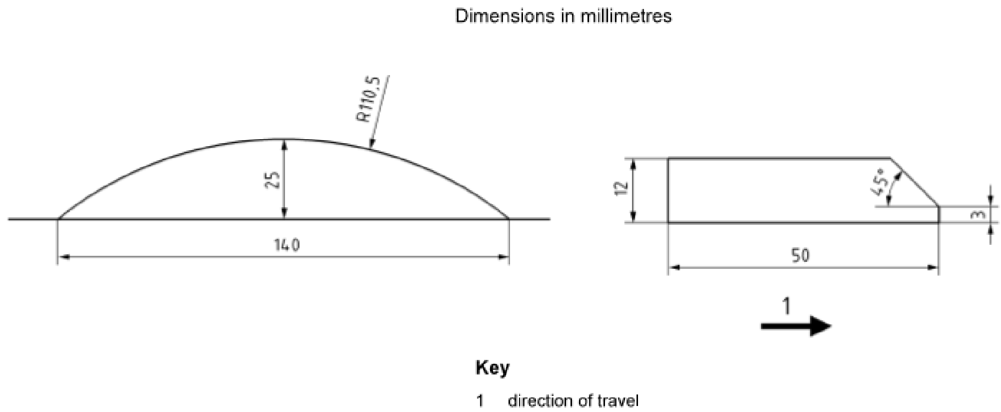
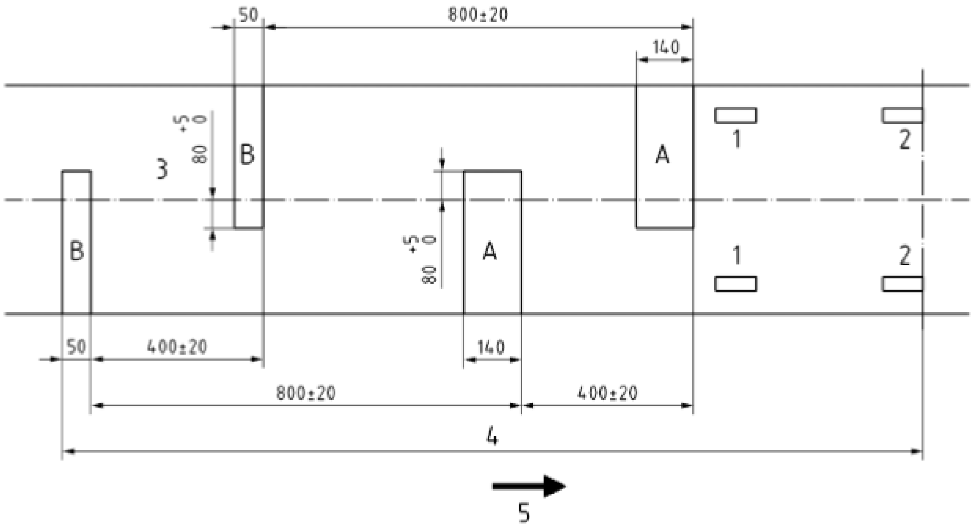


Figure 18 – Obstacle A to the left, obstacle B to the right

Dimensions in millimetres



Key

1 front wheels
2 back wheels
3 centre line
4 length of 1 cycle
5 direction of the travel of obstacles

Figure 19 – Configuration of Irregular surface test

5.3 Mapping Thule’s stroller route before testing

5.3.1 **Purpose**

Knowing what grounds covered Thule’s two tracks could lead to an understanding of in which ways different grounds affected the stroller.

5.3.2 **Method**

Previous testing with users had given a method to map the grounds and obstacles on Thule’s stroller routes. This time it had to be done more precisely to be able to compare collected data from the accelerometers with the route layout. Instead of making each ground a total sum, each distance with a different surface would be mapped as a part percentage of the entire route. For example: If the sensors show high acceleration 10 % in on the route, the mapping should show which ground was present at 10 % in. In this way, more precise conclusions could be drawn about what the stroller reacts to.

5.3.3 **Results**

5.3.3.1 Track 1

Track 1 was examined using a map on which different grounds were noted. The summary can be found in Table 9.

Table 9 - Summary of grounds on track 1, in order

Ground	***Covered (% unit)***	***Ground***	***Covered (% unit)***
Asphalt	0-10.5	Wood deck	30.1-30.8
Stairs	10.5-10.7	Woodland	30.8-41.6
Asphalt	10.7-11.6	Asphalt	41.6-49.5
Stairs	11.6-11.9	Steel	49.5-49.9
Asphalt	11.9-12.2	Asphalt	49.9-80.1
Stone tiles	12.2-12.3	Woodland	80.1-81.7
Asphalt	12.3-12.5	Asphalt	81.7-87.4
Coarse gravel	12.5-12.6	Coarse gravel	87.4-87.5
Asphalt	12.6-18.3	Asphalt	87.5-87.7
Woodland	18.3-19.9	Stone tiles	87.7-87.8
Asphalt	19.9-26.8	Asphalt	87.8-88.1
Small gravel	26.8-27.2	Stairs	88.1-88.4
Asphalt	27.2-28.0	Asphalt	88.4-89.3
Wood deck	28.0-28.6	Stairs	89.3-89.5
Small gravel	28.6-30.1	Asphalt	89.5-100

5.3.3.2 Track 2

The same method as before was used and the summary is seen in Table 10.

Table 10 - Summary of grounds on track 2, in order

Ground	*Covered (% unit)*	*Ground*	*Covered (% unit)*
Asphalt	0-22.8	Small gravel	39.8-41.9
Coarse gravel	22.8-23.6	Wood deck	41.9-42.1
Asphalt	23.6-23.9	Asphalt	42.1-46.1
Coarse gravel	23.9-24.8	Woodland	46.1-49.3
Asphalt	24.8-28.0	Asphalt	49.3-62.0
Small gravel	28.0-29.7	Woodland	62.0-79.5
Woodland	29.7-39.7	Asphalt	79.5-100
Asphalt	39.7-39.8		

5.3.4 **Discussion**

The data can’t be considered reliable since it was challenging to mark the map accurately and objectively. This way of mapping is not effective when measuring precisely over a large distance. There are too many factors in play: how fast does the stroller go, which obstacles does the test person encounter etcetera. To get an actual understanding of the tracks, they would have to be measured while testing the stroller – not before. If a camera would be fastened on the stroller, the data from the accelerometers could be compared in retrospect to the timeline of the camera. This will not be done during this master thesis since it won’t add much value when comparing the different test methods.

When the tracks’ grounds are compared with those collected from users in chapter 3, it’s clear that they don’t cover the same things. For example, none of the tracks has paving stone. This seems like something Thule should test since urban users are likely to subject their strollers to paving stone and it could possibly result in higher vibrations in strollers. Small gravel and stone tiles are also underrepresented. Even if the user tests weren’t sufficient for a complete user profile, it seems Track 1 and 2 represent a specific kind of user, not a majority. The tracks will still be measured for comparison with IrregularST.

5.4 Testing Thule Sleek

The stroller was tested with accelerometers on Track 1 and 2 in Hillerstorp and on IrregularST. The configurations in Table 8 were followed.

5.4.1 **Track 1**

Track 1 was measured multiple times with the two different configurations for comparison, but also because the accelerometers and the stroller prototype sometimes malfunctioned which compromised the data.

5.4.2 **Track 2**

Track 2 was measured fewer times than Track 1 since nothing malfunctioned during this route, and because it was more time consuming. Configuration 2 was only measured once.

5.4.3 **IrregularST**

The stroller was mounted on the treadmill and rolled over the obstacles for five minutes for each configuration. This was deemed sufficient time for such a repetitive test since no larger variations occurred.

5.4.4 **Discussion**

To make the data comparable, it was important to try to walk as closely to 5 km/h as possible, like the speed in IrregularST. This turned out to be difficult as soon as the ground changed from, for example, asphalt to coarse gravel, or in steep hills. This lead to the data not being perfectly comparable.

When measuring on the mass, it wasn’t possible to accurately keep the accelerometers in Thule’s predefined directions. This was because the mass shifted a lot in the seat during testing. The seat itself was not fixed but swayed while walking over obstacles which caused the sensors to not be leveled.

The double-sided tape wasn’t secure enough to hold some of the accelerometers in place since many of them fell off during walks. It had to be complemented with other tape and covering plastic so that gravel wouldn’t make the tape less adhesive.

6 Analyzing data

6.1 Purpose

After data was acquired with accelerometers, a way to compare the data was required. The method used needed to make the information interpretable and comparable so that similarities and dissimilarities could be discussed.

6.2 Method

6.2.1 Researching to find a suitable method

6.2.1.1 Filter and frequencies

When data from the sensors was collected, a filter which would clear the data of potential misreadings and background noise should be constructed. A bandpass filter was suitable for this, since it can eliminate both higher and lower frequencies [23]. The problem is knowing which cut off frequencies, seen in Figure 20, to use. The frequencies within the passband is included and then gradually phased out.

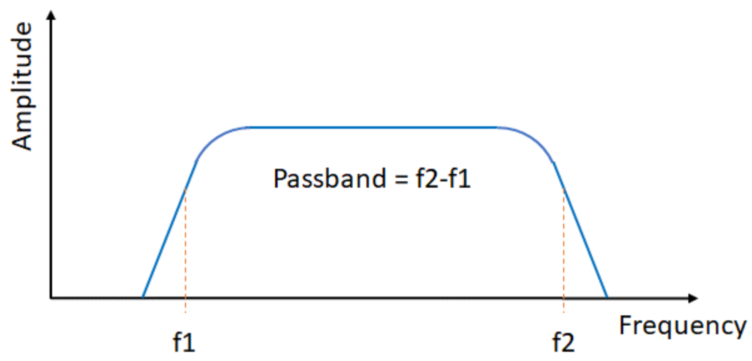


Figure 20 - Function of a bandpass filter, with cut off frequencies before f1 and after f2

As mentioned earlier, 0.5-50 Hz is used in the car industry, but a stroller is a completely different entity with other potential hazardous frequencies. To see which frequencies were present during measuring, Fast Fourier Transform – FFT – was used. FFT is a way to determine which frequencies a signal is made of, and to see which one of them is most dominant [24]. The FFT could give an indication of how the filter should be designed. A visual explanation of how a FFT works can be found in Figure 21.

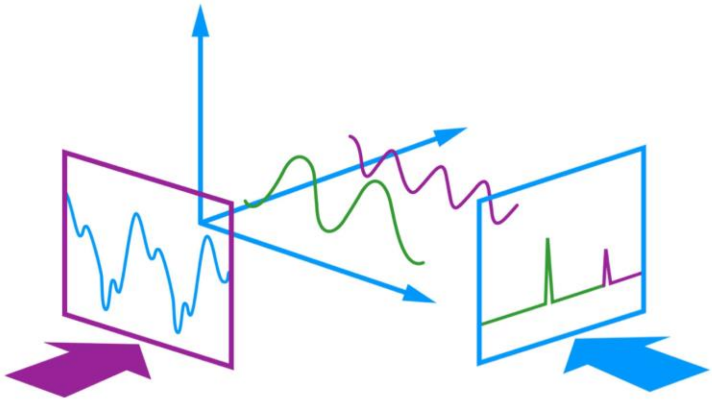


Figure 21 – Visual representation of what a FFT does. The signal on the left is representing the data acquired from accelerometers. The FFT can be used to divide the signal in partial signals which can be read on the right as the different frequencies the signal consists of. A higher FFT peak indicates higher energy which means that it's more dominant in the signal. (Retrieved June 4, 2018, from https://www.tes.com/lessons/WB4DKRQi1KBAMQ/eee208-workbook-and-notes).

The goal was to find a way to easily compare graphs from the tracks to the graphs obtained from the IrregularST to see if they match. Comparing them was the challenge, which is why a doctoral student with knowledge regarding the subject, William Rosengren, was contacted. He and a colleague suggested a range of relevant ways to compare data, but too complicated for this master thesis. The conclusion was to find a "fingerprint" for each accelerometer's data, which was to be compared to find a level of matching between Track 1/2 and IrregularST [25].

6.2.1.2 Software

A suitable program for designing all the above was MATLAB. To filter data, design code and analyzing the result in said program, some outsourcing was made. A supervisor at LTH – Lunds Tekniska Högskola – was contacted. With him, function and esthetics regarding the code were discussed to increase usability [26].

6.2.2 **Finding a suitable method using FFT:s and Acceleration-graphs**

Acceleration- and FFT-plots were constructed to get an indication of how to design the filter and code. The preliminary cut off frequencies were 0.5-50 Hz.

6.2.2.1 Configuration 1

In Figure 22 there is an example of how the filtered and unfiltered acceleration plots looked on the right back wheel in x-direction. The x-axis is time and the y-axis is acceleration. Track 1 and 2 have been marked with descriptions of grounds and obstacles near higher peaks.

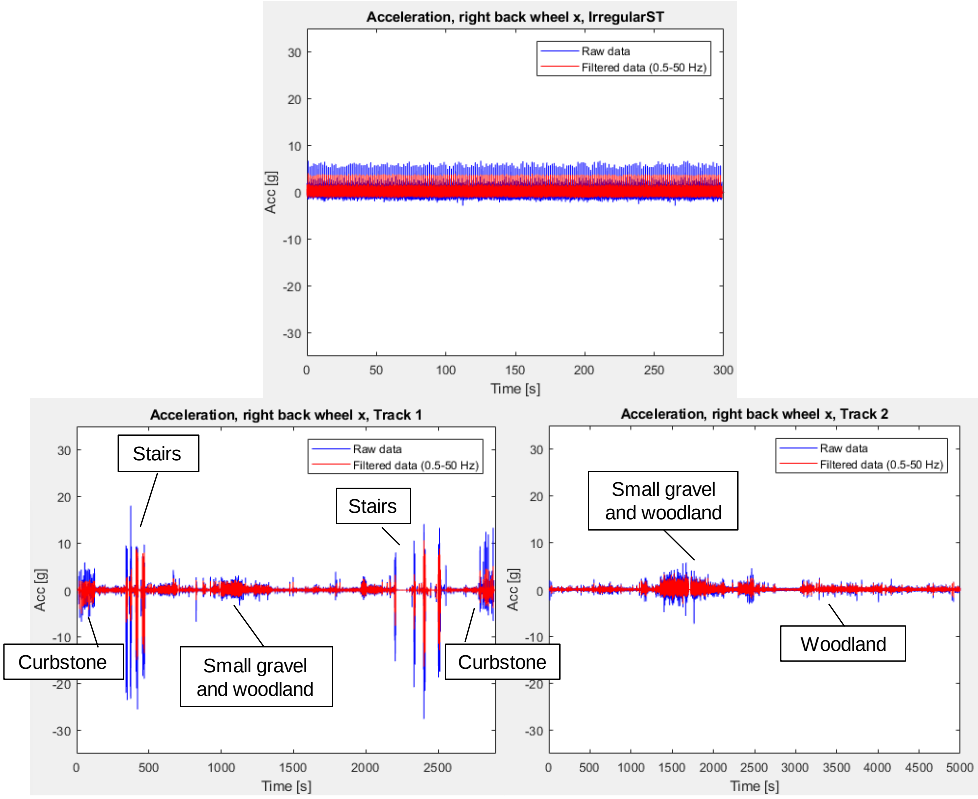


Figure 22 - Shows the filtered (red) and unfiltered (blue) acceleration for the sensor on the right back wheel in x-direction for IrregularST, Track 1 and Track 2 in configuration 1.

The IrregularST has a regularity in the unfiltered acceleration around 7g. The graph doesn't show much acceleration in negative direction (the travel direction of stroller). Track 1 shows larger unfiltered peaks at about 20g and -30g during stairs, but most of the time displays less acceleration than the IrregularST. Track 2 doesn't show higher unfiltered accelerations than in IrregularST for almost the entire time, but is similar near small gravel and woodland. When introducing a trial bandpass filter of 0.5-50 Hz the peaks decreased in value. IrregularST shows a constant maximal acceleration around 4g. Track 1 has its highest peaks around 10g and -20g, and Track 2 around 4g. The overall shapes of the graphs are the same. Acceleration graphs for the other sensors, and a discussion about their appearance, can be found in Appendix D.1.

In Figure 23 are FFT:s for the entire length of all measurements on the right back wheel in x-direction. The x-axis is frequency and the y-axis can be called amplitude (note that it is not the amplitude of the oscillation). The IrregularST shows fewer frequencies than the tracks and more dominant frequencies around 1-25 Hz, while for Track 1 and 2 it's around 1-60 Hz and 1-40 Hz. The FFT graphs for the other sensors, and a discussion about their appearance, can be found in Appendix D.2.

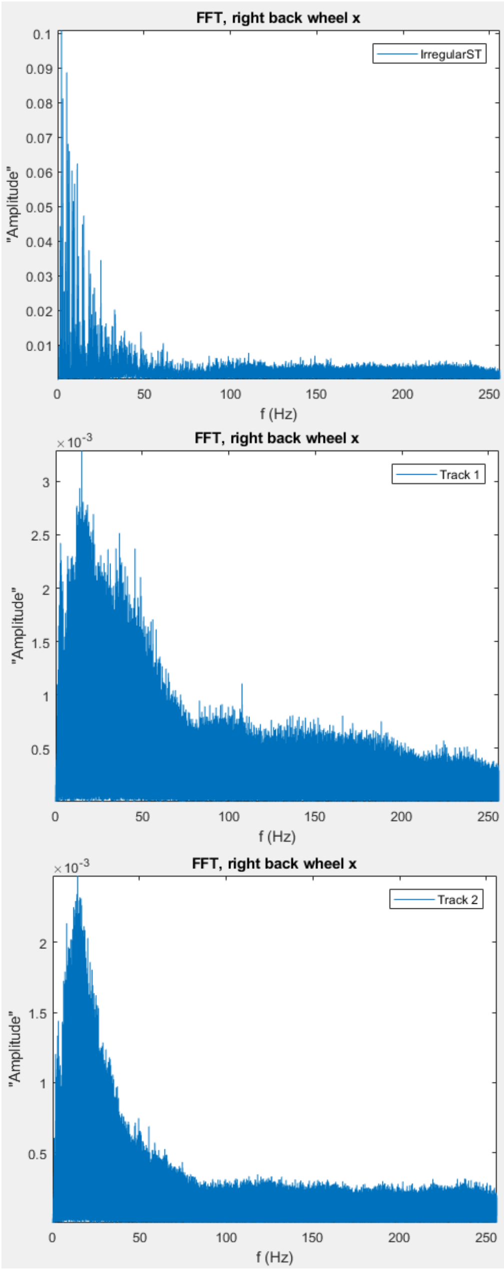


Figure 23 – Shows the FFT for the sensor on the right back wheel in x-direction for IrregularST, Track 1 and Track 2, configuration 1.

6.2.2.2 *Configuration 2*

Configuration 2 displayed lower acceleration which is why the y-axis was decreased. Filtered and unfiltered data for the mass in x-direction was placed in the same plot for easier comparison, see Figure 24.

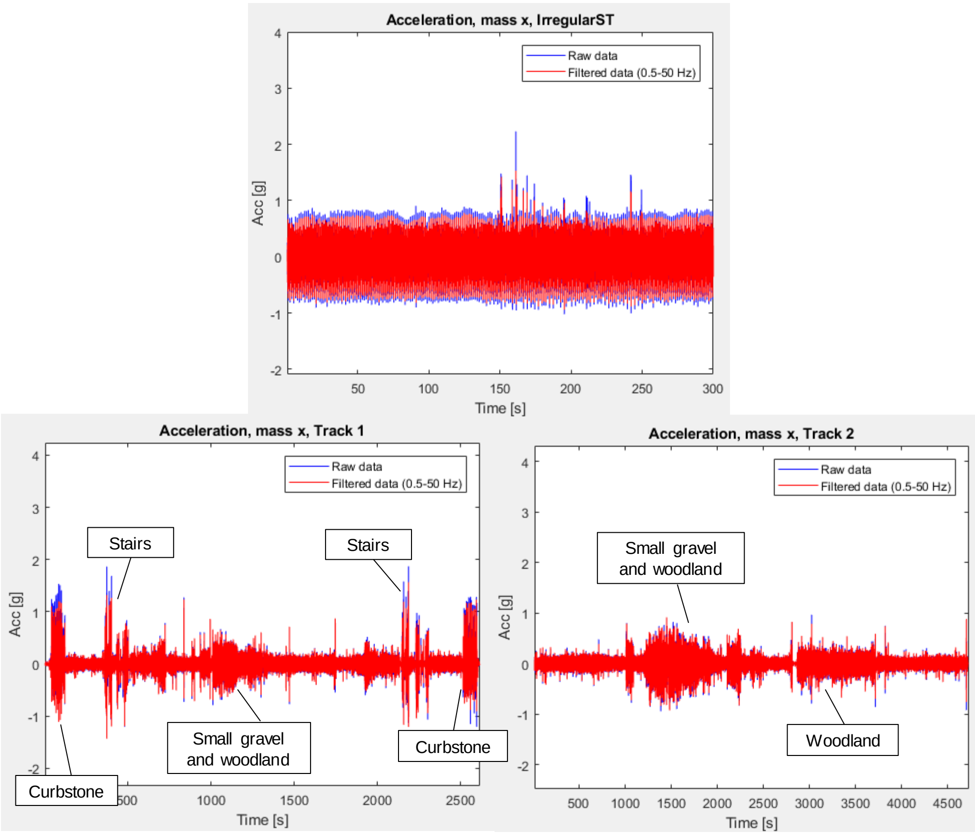


Figure 24 – Shows unfiltered (blue) and filtered (red) acceleration for the sensor on mass center in x-direction for IrregularST, Track 1 and Track 2, configuration 2.

The graph shows that filtering has very little impact on the data. It also shows that the mass has much lower acceleration than the wheels when compared to Figure 22 and 23. The highest peak (around 2g) in Track 1 occurs during stairs. In IrregularST there is a peak at 2g, which seems to be random. IrregularST is mostly between 0.8g and -0.8g which is around the highest acceleration Track 2 shows during small gravel and woodland. The acceleration graphs from other sensors, and a discussion about their appearance, can be found in Appendix D.1.

In Figure 25 are FFT:s for the mass center in x-direction. The most dominant frequencies seem to be around 1-20 Hz for all plots. The FFT graphs for the other sensors, and a discussion about their appearance, can be found in Appendix D.2.

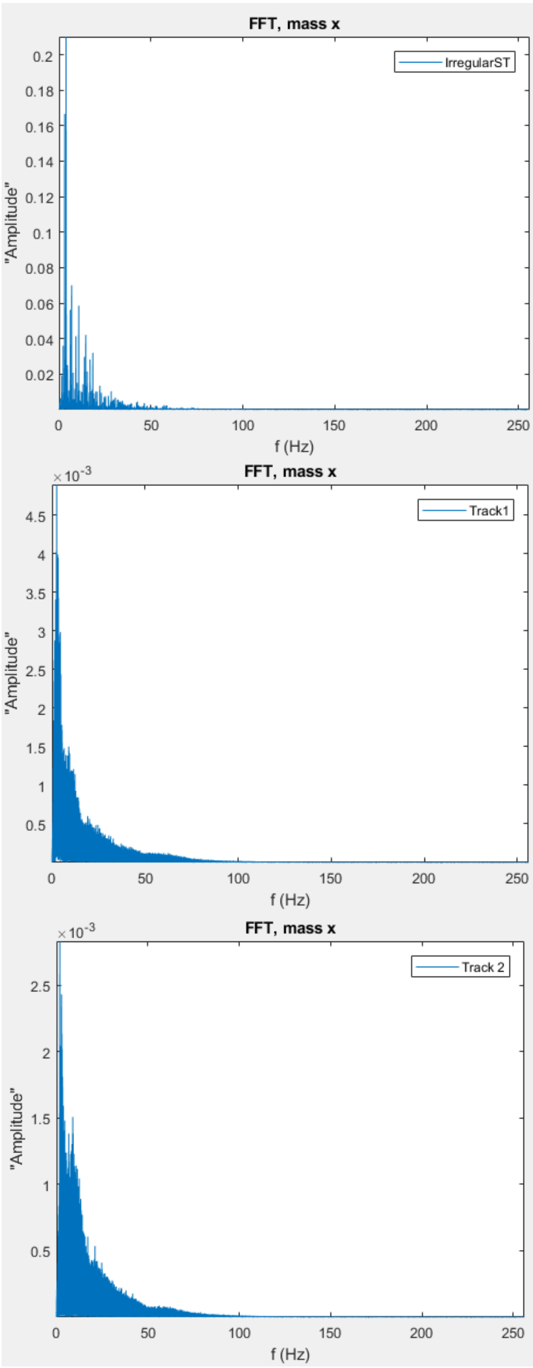


Figure 25 - Shows the FFT for the sensor on mass center in x-direction for IrregularST, Track 1 and Track 2, configuration 2.

6.2.3 Conclusion

After studying the FFT:s for each sensor in Appendix D.2 on each track and IrregularST it was clear that there was no distinct frequency span to adapt the bandpass filter to. Even if a lot of the tracks' FFT:s had the most dominant frequencies around 1-50 Hz in configuration 1, and around 1-20 Hz in configuration 2, there were still many other interesting frequencies present. In configuration 1 there where frequencies well over 100 Hz. The IrregularST's FFT:s had mostly dominant frequencies around 1-20 or 1-25 Hz. Since all data should be filtered in the same way to make the data comparable, the various frequency spans offered a challenge.

Seeing that the goal was to compare graphs with each other, it was decided that no filtering was needed. Multiple data from the same measurements showed no larger deviation which indicated that a filter wouldn't change the acceleration graphs to a more comparable state. As seen in the acceleration plots in Appendix D.1, they still had a similar appearance after filtering which is why this was considered reliable. However, the acceleration plots contained many variations which made them harder to compare to one another.

The FFT:s on the other hand gave a simpler overview. The "fingerprint", mentioned in chapter 6.2.1.1, was therefore decided to be a graph representing peaks of the FFT. This became the method of evaluating data. Each accelerometer's data from IrregularST, Track 1 and Track 2 would be found in one graph for comparison. This was considered a fast and easy way to see how similar the results were. The peaks were defined in MATLAB as the highest value found within the length of the x-axis divided with the number of frequencies. In other words, the program found the highest peak within the span of 1 Hz at a time. This would lead to some peaks being left out, but it was still considered the best way to get a clear visual representation of the FFT:s.

6.3 Result

The results for comparing data from accelerometers are peaks of FFT:s plotted in corresponding accelerometer graphs.

In Figure 26 and 27 is a frequency peak comparison between Track 1, 2 and IrregularST in configuration 1 plotted in the same graph. The same for configuration 2 is found in Figure 30.

In Figure 28 and 29 the two tracks are in the same graph, while the IrregularST is by itself. The same for configuration 2 is found in Figure 31. This increased readability.

6.3.1 Comparison FFT in same graph, configuration 1

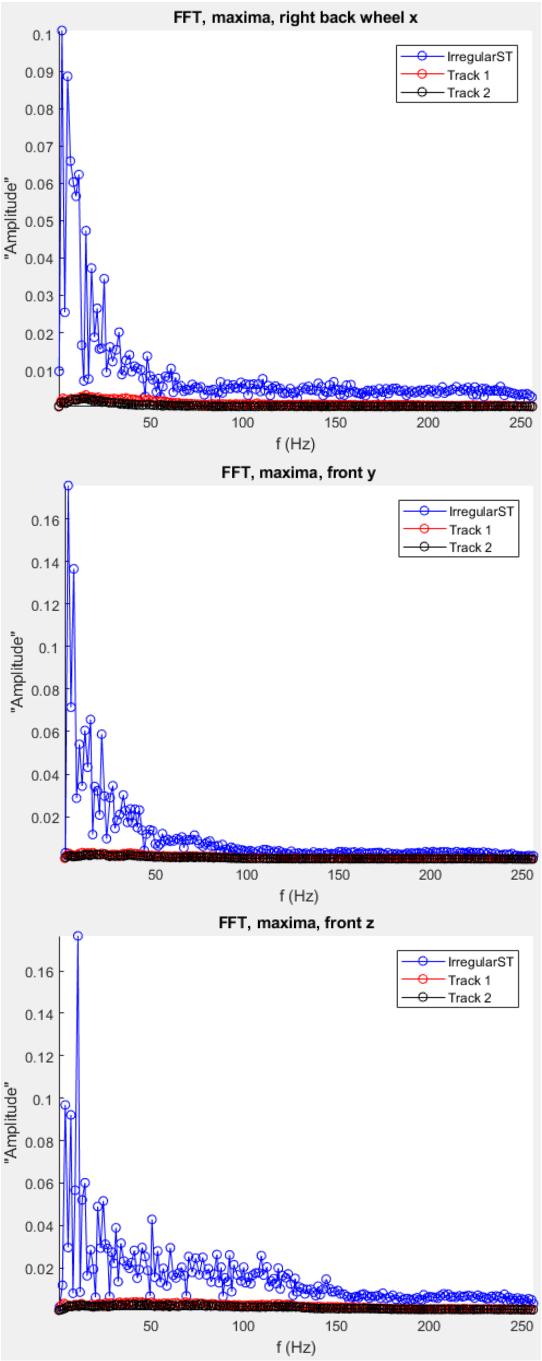


Figure 26 - The highest peaks from FFT:s from accelerometer 1, 2 and 3 on IrregularST and Track 1/2, configuration 1.

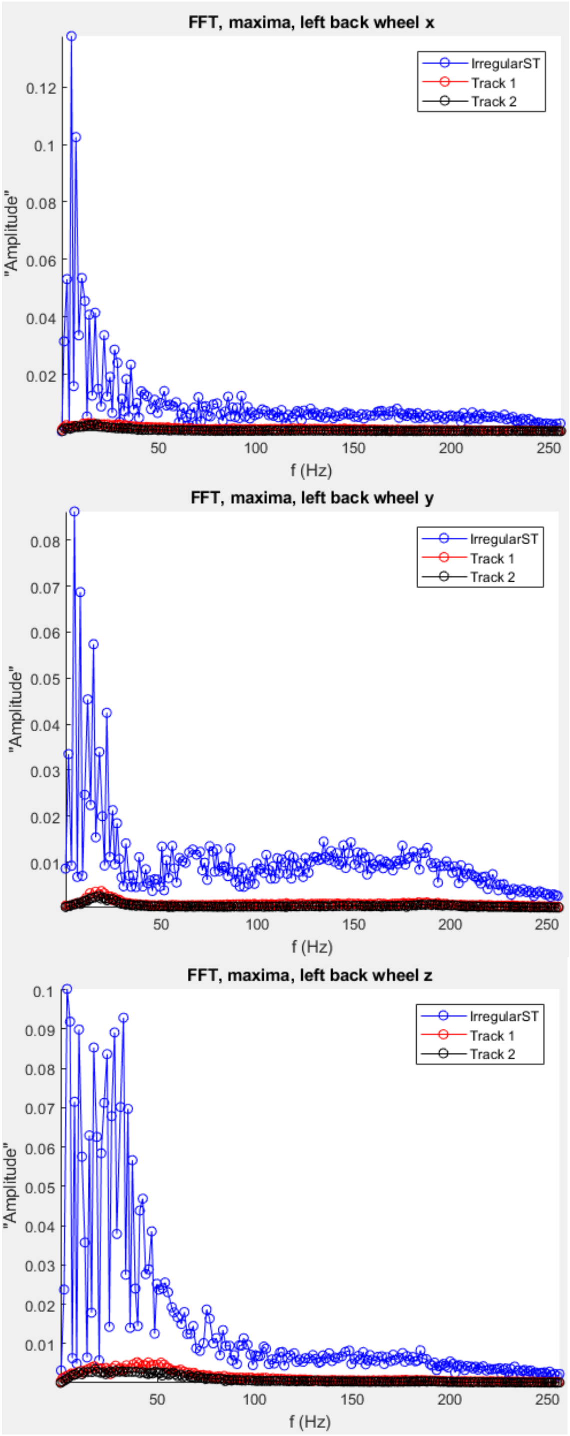


Figure 27 - The highest peaks from FFT:s from accelerometer 4, 5 and 6 on IrregularST and Track 1/2, configuration 1.

6.3.2 Comparison FFT in different graphs, configuration 1

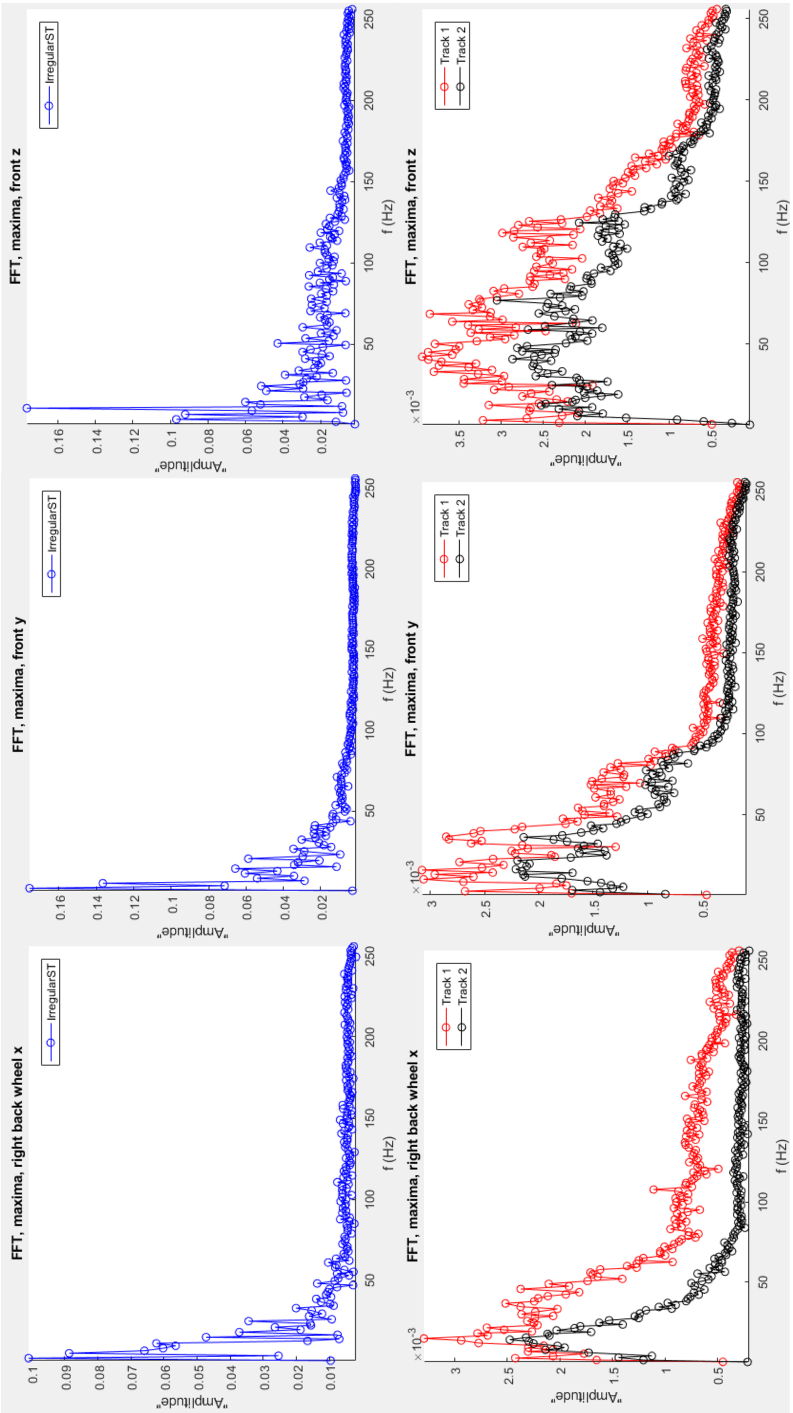


Figure 28 – The highest peaks from FFT:s from accelerometer 1, 2 and 3 on IrregularST (blue) and on Track 1/2 (red and black), configuration 1.

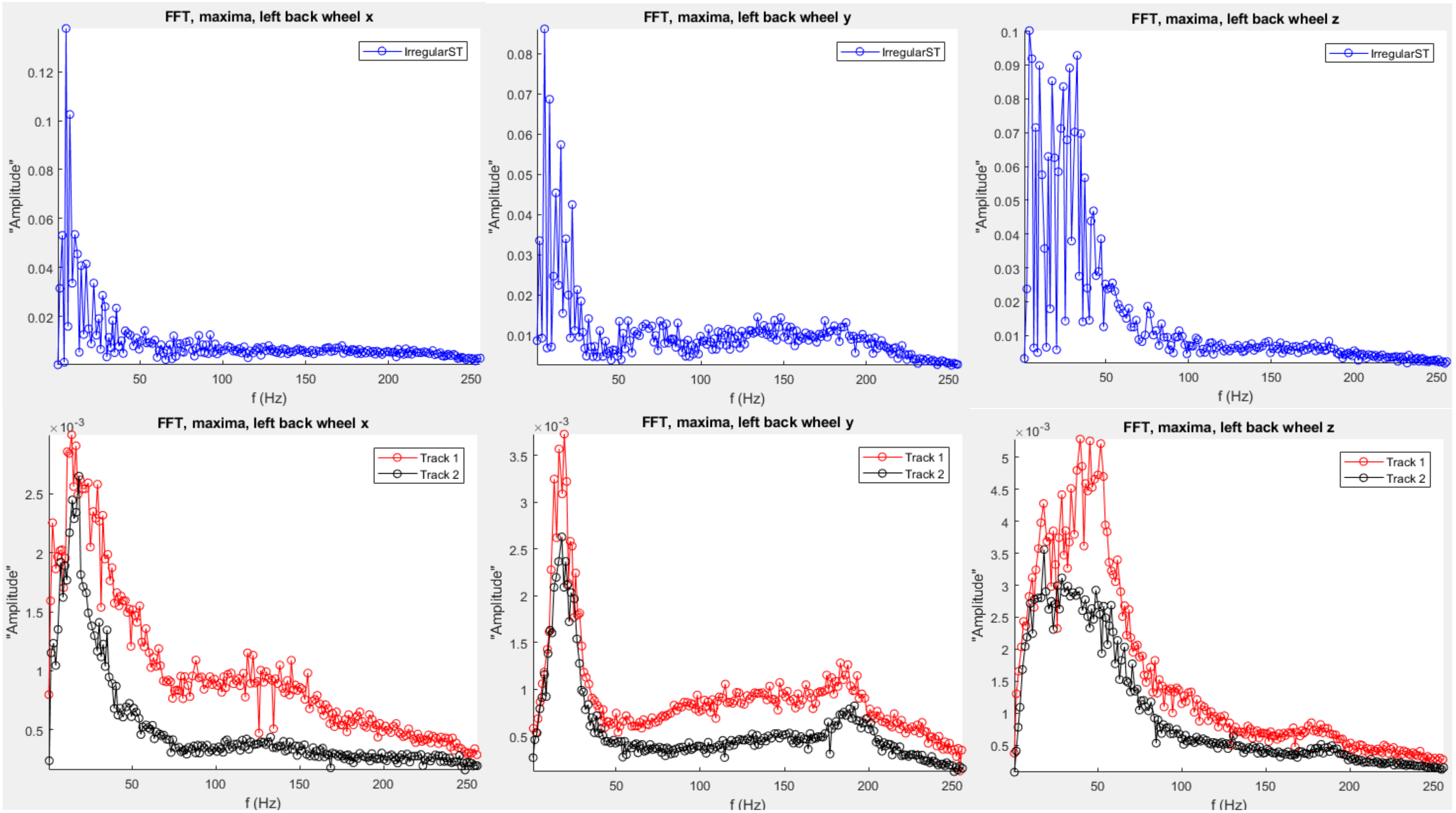


Figure 29 – The highest peaks from FFT: s from accelerometer 4, 5 and 6 on IrregularST (blue) and Track 1/2 (red and black), configuration 1.

6.3.3 Comparison FFT in same graph, configuration 2

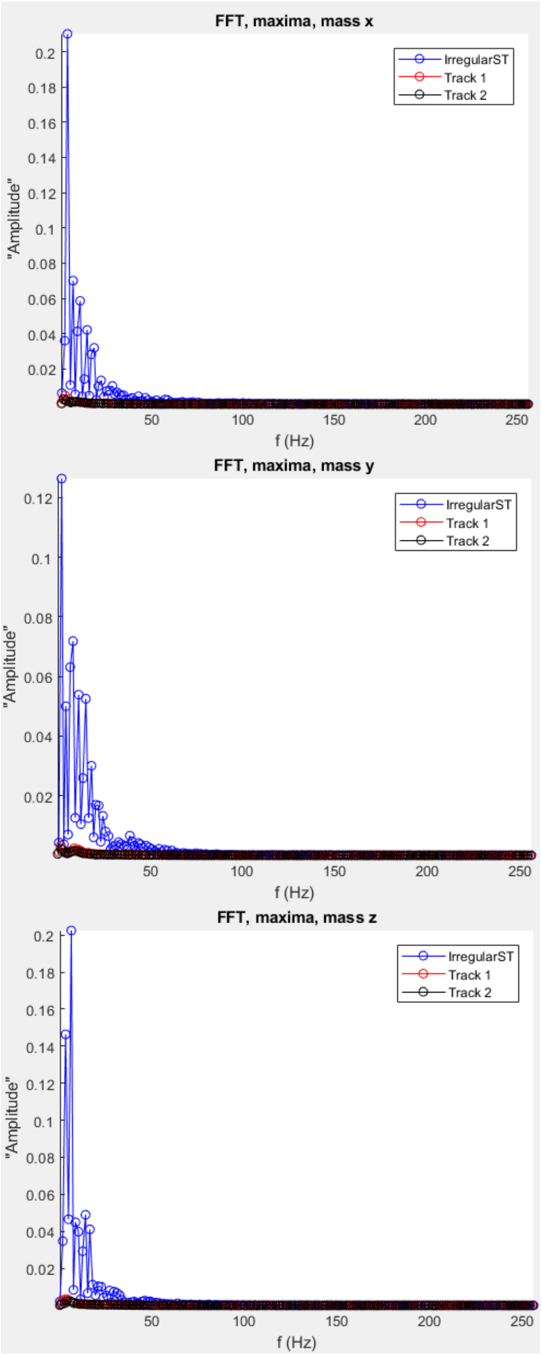


Figure 30 - The highest peaks from FFT:s from all accelerometers on IrregularST and Track 1/2, configuration 2.

6.3.4 Comparison FFT in different graphs, configuration 2

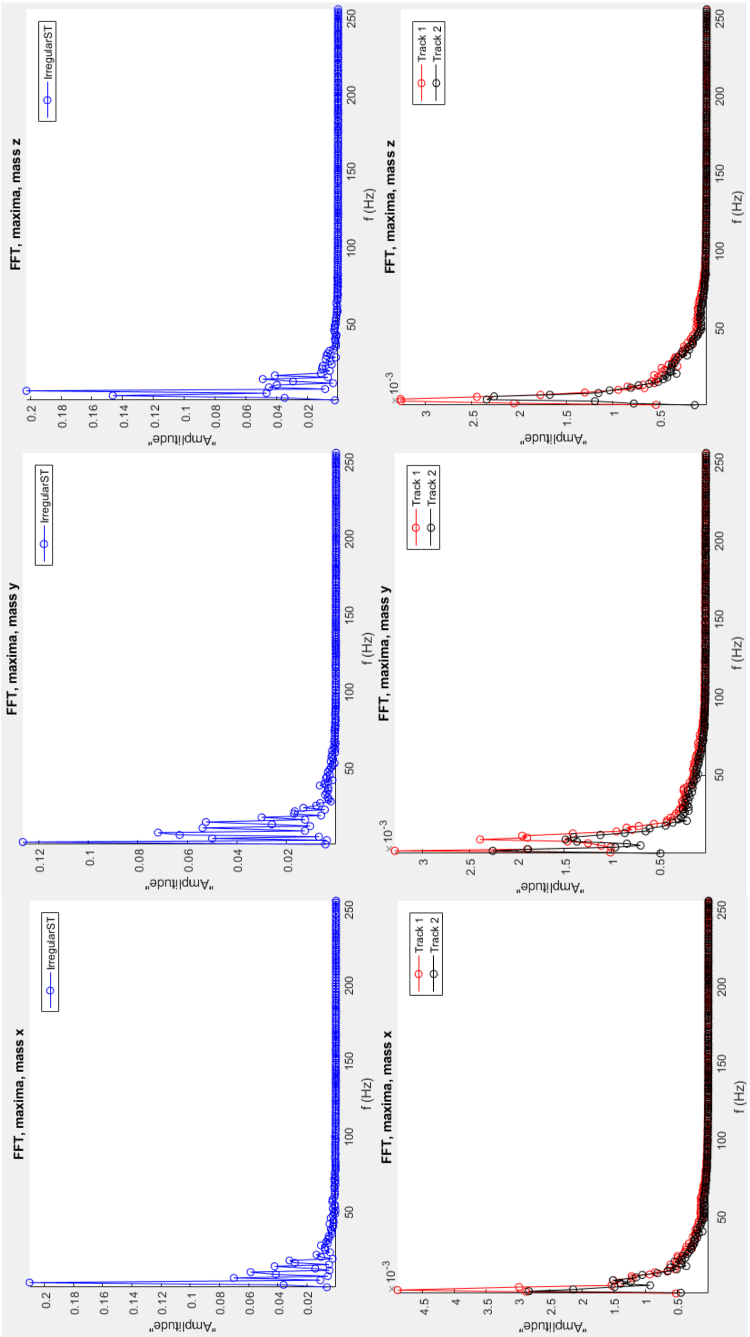


Figure 31 – The highest peaks from FFT: s from all accelerometers on IrregularST (blue) and Track 1/2 (red and black), configuration 2.

6.4 Evaluation of data

6.4.1 Configuration 1

In Figure 26 and 27 the amplitude for IrregularST is clearly a lot higher than for the tracks, sometimes more than 50 times higher. Perhaps this indicates that, even if similar frequencies occur during both tracks and the IrregularST, they occur more often in the test which makes the overall frequencies in the signal more dominant. This could happen since the acceleration graph from IrregularST shows the same accelerations during the entire time, but the tracks show a higher variety of acceleration and thereby not as prominent frequencies. It could also be because the stroller rolls more freely during IrregularST while during the tracks, the person rolling the stroller dampens the force at impact just by holding it. This could possibly lead to the stroller falling harder after a bump on the IrregularST than in real life, and therefore show a higher amplitude in the FFT. More knowledge needs to be found regarding this, since these are only guesses.

When looking at Figure 28 and 29 the specific frequencies becomes clearer. The IrregularST always have more dominant frequencies just a bit below the frequencies of the tracks. They are still quite similar, but the tracks seem to have been subjected to much higher frequencies. One interpretation of this could be that the IrregularST doesn't subject the stroller to as damaging frequencies. This doesn't seem likely though since, even if the test subjects the stroller to lower frequencies, it seems to expose the stroller to more energy (a higher amplitude). And as mentioned in chapter 3.4, a higher frequency doesn't have to be more damaging. There is no indication if the slightly higher frequencies of the tracks are more harmful to the stroller.

When looking at all comparisons between the two tracks, there's an indication that Track 2 affects the stroller the least. It practically never has an acceleration over IrregularST, and is always below Tracks 1:s amplitude in all the FFT:s. The two tracks have quite similar appearances in the FFT:s though, which indicates that the stroller behaves similarly regarding frequency even with variations in the ground. From the plots for Track 1 and 2 in Appendix D.1 it can be deducted that acceleration during curbstones, woodland and small gravel is similar to the acceleration during IrregularST.

6.4.2 Configuration 2

Figure 30 shows that IrregularST generates a much higher amplitude in the FFT:s than for Track 1 and 2, sometimes 60 times higher. But Figure 31 shows a high resemblance between the tracks' and IrregularST's dominant frequencies. Track 1 and 2 are almost identical where Track 1 sometimes has a higher amplitude. As said in evaluation of configuration 1, it's not clear why the IrregularST shows a much higher amplitude. A future filter for testing on the mass could be around 1-25 or 1-20 Hz since no other interesting frequencies seem to be present.

Earlier it was mentioned that measuring on the mass would be interesting to evaluate the comfort of the child in the stroller seat. It looks like the seat dampens the higher frequencies which is probably comfortable for the child. The dangerous frequencies between 2.5-3 Hz with an amplitude of 50 mm doesn’t seem to occur. Even if the frequency span occurs, the amplitude was never as high as 50 mm (note that this is not the amplitude in the FFT) during testing. It would also have to happen during a few consecutive seconds, which none of the tracks or IrregularST implied it did.

7 Conclusion & Discussion

This master thesis has been a project comparing the IrregularST with Thule's tracks in Hillerstorp to see if they match. An important question to answer is if the IrregularST, Track 1 and 2 mirror the use of Thule's customers. The answer is that no finite conclusions can be drawn from the data obtained. There would have to be more analyzing of data in various ways, which are discussed below. The following is the conclusion based on the collected data.

The IrregularST and the two tracks in Hillerstorp seem to be testing different things. The IrregularST is aimed towards testing durability over a long period of time, whereas the tracks are for testing a simulated user situation during a short period of time. The IrregularST will affect the stroller constantly at a relatively low level of external impact. The tracks mostly have a very low impact, with few moments with notably high external force. It seems like IrregularST nearly simulates gravel, curbstones and woodland, but nothing else, on the tracks when looking at peaks in the acceleration plots. When looking at FFT:s, it seems like IrregularST and the tracks are equivalent only when measuring on the mass. All mass acceleration plots are also more alike than when measuring on the wheels.

The premise of the comparison between IrregularST and the two tracks is that the tracks are a representative image of Thule's customers use of their strollers. According to the limited data collected from real users, this is not the case. For example, the tracks don't have paving stone at all. They don't nearly cover as much small gravel and stone tiles as the user tests suggest they should. The tracks are fine for testing strollers under development to see if they feel good to use, if they hold together during the tougher parts and to quickly discover any lack of safety. But if Thule wants to test user experience more accurately, a shorter track containing various grounds should be included in future testing. In this way, one could easily roll the stroller over several grounds in a short period of time. That could give an estimate of how the stroller copes with all grounds, regarding user experience.

A recommendation to Thule would be that they define their customers' needs more accurately. When knowing how their strollers are used they could put together a general customer profile for urban users and countryside users with a percentage of which grounds the stroller is subjected to. They could also more precisely define a life span for each stroller when knowing what it is subjected to. The grounds could be mapped using accelerometers and then the data could be transferred into a vibrating table which the stroller could be mounted upon. Thule already owns a vibrating table and perhaps it could be used for testing strollers. This could save

Thule a lot of time and manpower since walking the tracks repeatedly requires both. The tracks, the IrregularST and an eventual standardized customer profile test would greatly complement each other seeing that they cover different scenarios.

Even if this study didn’t have to be repeatable for comparing the different tests, these results only show what happens when measuring on one stroller. It was also performed by the same person throughout testing. The study would have to be repeated with other strollers or test persons to confirm the data, and finding a way to make the process repeatable would simplify that process.

To make all tests with accelerometers repeatable, a few changes would have to be made. Firstly, the placement of the sensors would have to be specified for all kinds of strollers. The placement could be on only the mass to test comfort and such. It would be important to secure the mass in the seat even more so that it doesn’t move around. On an eventual vibrating table, some of the accelerometers should be placed close to the wheels since that would show if the frequencies from the vibrating table are transferred up in the stroller body accurately. This could be standardized since all strollers have wheels and a test mass in the seat during testing. The most interesting directions to measure seems to be in z-direction for the wheels and triaxially on the mass.

It looks like the mass isn’t exposed to a lot of acceleration according to the obtained data. But compared to the wheels the mass has a much higher weight. A higher frequency on something with low mass doesn’t have to be as damaging as lower frequencies on a heavy object. Measuring on the mass leads to more comparable graphs, which indicates that the mass is the measure point best represented during IrregularST. Even so, it seems important to make sure the entire stroller is represented during testing since breakage in any part can lead to child injuries.

Further work could be to calculate partial damage during IrregularST and the tracks. This could give an idea of how much of Track 1 and 2 matches the partial damage of IrregularST. A clearer “fingerprint” could be defined, using MATLAB to find a way to compare a segment in the acceleration plots of the IrregularST with parts of Track1/2 to in the end get a percentage of how much they match. Based on the current graphs, the guess is that they wouldn’t match much. A comparison in the FFT:s would perhaps be more relevant since they show a summary of which frequencies are most prominent during all tests. The problem here is how to interpret the fact that the amplitude of the FFT:s for IrregularST sometimes is more than 50-60 times higher than of Track 1 and 2. If they show similar frequencies but completely different amplitudes – are they then comparable? More research would have to be done in this area with people possessing more knowledge regarding FFT and frequencies.

8 Thoughts about master thesis

8.1.1 Difficulties and challenges

The master thesis lasts for 20 weeks which isn't a long time relative to the extent of the project.

It took time before becoming more self-sufficient and less relying on Thule's input, and it was hard to find any previous studies regarding the subject. Trying to understand what Thule sees for themselves in the future regarding strollers was challenging since they are relatively new to this.

The process, that I thought would be straight forward, turned out to be iterative with many parallel projects going on at the same time. The project was quite sizable in the beginning and during the entire process numerous delimitations had to be made which changed the directions of the project. This was sometimes confusing and made it hard to see were the project was going, even if it was absolutely necessary. Some parts that took a lot of time turned out weren't relevant to the outcome of the master thesis and some parts were left out due to lack of time. This could perhaps have been avoided if a clearer project description had been made earlier. A lot of time was spent waiting for answers when contacting people outside of the project for information, and some people never answered at all.

Not living near Hillerstorp was a challenge. While I was there a lot of work was done, questions were answered fast and extensively, and if something went wrong I could fix it straight away. In Lund it was much harder to find things to do every minute of the day since I waited for people to get back to me and because I didn't have access to any equipment.

I wasn't allowed to use some of the equipment myself. Fortunately, the employers at Thule often aided me when I needed it even if they themselves had a busy schedule.

8.1.2 Reflection

Relative to the extent of the project I am happy with how far the project came along. During the project I was less happy since I wanted to solve every problem presented to me and give Thule a great advantage on today’s market. I wish the results were more conclusive, but I think that some of it might be of use for the company anyway. Hopefully, other master thesis students can take over where I left off. Personally, I have learned a lot about how a real workplace works and how testing and development is done at Thule. I’ve learned more about how accelerometers work which will hopefully be of use to me in the future.

If I were to do this project all over again I would define the project more clearly in the beginning. I would choose to either focus on customer profiling or analyzing data since both entails extensive work. I would make sure that I live near the company I work at which would increase my efficiency. I think I would have worked with another person to exchange ideas with continuously.

I think I followed the time plan quite well, but there were a few major changes. More on this can be read in Appendix E. Planning absolutely helps to guide the project, but one must be prepared that nothing will happen as you thought it would.

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Appendix A Pilot test first draft

A.1 The form

Pilottest - 2 delar (kontextuell)

- Praktisk - anteckna vad barnvagnen utsätts för SAMT hur den används.
- Teoretisk - intervju med användaren om hur denne använder barnvagnen

Praktisk

Trottoarkanter:
Trappsteg:
Gupp:
Gropar:
Stöt med föremål:
Barnet studsar:
Barnet står på "fel" ställe:
Övrigt:

Meter asfalt:
Meter grus:
Meter gräs:
Meter jord:
Meter sand:
Meter snö/is:
Meter kullersten:
Meter stenplattor:
Meter trädäck:
Meter skogsmark:
Meter övrigt:

Anteckningar och kommentarer

Teoretisk

Namn:
Ålder:
Yrke:
Kön:
Ort:
Antal barn resp. ålder:
Vilken sorts vagn:
Vem bestämde vilken vagn som skulle inköpas?
Hur länge har du haft vagnen?
Varför valdes den vagnen?

Vilket/vilka barn använder vagnen?

Om du har barn som ej sitter i vagn, följer de med ut på promenader med vagnen?
Hur beter de sig kring vagnen?

Varför använder du barnvagn?

Vad har du för förväntningar på en barnvagn?

Hur fungerar den enligt dina och barnens behov tycker du?

Vilka funktioner är du mest tacksam för?

Vilka funktioner anser du är onödiga?

Vilka mer än du använder vagnen? Om andra använder den - hur ofta använder de vagnen?

Vilken är den mest extrema situation vagnen har utsatts för?

Finns det tillfällen då vagnen känts osäker? Varför?

Finns det tillfällen då vagnen känts oergonomisk? Varför?

Har du hört talas om Thule? Vad tänker du i så fall när du tänker på Thule?

Anteckningar och kommentarer

Appendix B User test form, country

Test av barnvagn

Undersökning av statiska och dynamiska belastningar på en barnvagn.

Bakgrund

Hej!

Jag är en civilingenjörsstudent som för närvarande genomför ett examensarbete på Thule Sweden om barnvagnar. Arbetet handlar om att kartlägga vilka statiska och dynamiska belastningar som kan förekomma på en barnvagn under exempelvis en promenad. Arbetet kommer förhoppningsvis leda till en större förståelse för hur tålig en vagn måste vara för att uppfylla användares behov. Den insamlade datan kan komma att användas av Thule för att främja deras utveckling av framtida produkter. I rapporter och redovisningar kommer era svar att behandlas anonymt. Undersökningen är frivillig.

Vid frågor är det bara att ringa 0725–774425 alla vardagar mellan kl. 9-17 eller mejla julia92rosengren@gmail.com. Jag svarar gärna på alla de frågor som skulle kunna uppstå!

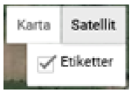
Nedan följer 3 olika delar som ni gärna får besvara så noggrant ni kan för att hjälpa mig med min kartläggning. Den första delen kräver tillgång till internet och kan ta lite tid bl.a. beroende på hur ni har använt er barnvagn. Den är utformad på ett sätt så att ni ska slippa göra så mycket som möjligt av mitt arbete. Del 2–3 är intervjufrågor.

Tack för er hjälp!

Del 1 - kartlägga runda

För att effektivt kunna kartlägga vilken sorts terräng (asfalt, skogsmark, grus…) barnvagnen rullar på så får ni gärna följa nedanstående instruktioner:
OBS! Rundan ska helst vara mellan **1–5 km**! (Jag kommer senare att gå rundan och notera alla underlag och hinder).

- Var vänlig gå in på hemsidan *distansen.se*. Skriv in det geografiska området där du tagit en av dina mer utmanande* rundor med barnvagn och markera ut rundan du tog efter bästa förmåga. Se till att knappen ***Satellit*** är intryckt och att ***Etiketter*** är ikryssad.



*Med utmanande runda menas rundor som orsakat en större belastning på vagnen i form av gupp/gropar, trottoarkanter, svårare terräng m.m.

- Använd funktionen print screen** på din dator med kartan i **fullskärmsläge**. Skicka sedan bilden till mig via mejl och ange var rundan är samt ungefär hur lång tid rundan tar att gå i genomsnitt.

**Återfinnes på PC i form av en knapp PrtSc eller PrtScrn. Bilden klistras sedan in i ett dokument eller mejl med Ctrl + V.
På Mac används ⌘ + Shift + 3. Bilden återfinnes sedan på Skrivbordet.

OBS! Om hela rundan inte får plats i en bild, skicka då två (eller flera) olika bilder med delar av rundan på varje bild. Ha kartan så inzoomad som möjligt. Tänk på att jag tydligt måste kunna se hur ni har gått för att kunna göra en ordentlig kartläggning.

Del 2 – frågor om användning

Nedanstående frågor ställs för att få reda på kompletterande information om vilka *statiska och dynamiska* belastningar barnvagnen skulle kunna utsättas för under användning. Fyll i efter bästa förmåga:

Boendeort:

Antal barn resp. ålder (ange vilket/vilka av barnen som sitter i vagn):

Vilken sorts vagn har du?

Varför valdes den vagnen?

Om du har barn som ej sitter i vagn, följer de med ut på promenader med vagnen?

Om ja: Hur beter de sig kring vagnen?
(Ex. Står på vagnen, kör vagnen själva…)

Använder fler än du vagnen? Vilka?

Om ja: Hur ofta använder de vagnen? Anser du att de använder den på ett sätt som utsätter vagnen för större påfrestningar än vid eget användande? (Ge gärna exempel).

Finns det tillfällen då vagnen känts osäker? Varför?

Har det någonsin uppkommit skador på vagnen? Vilka och varför?

Har du någonsin varit tvungen att reparera vagnen? Varför?

Del 3 – egna kommentarer

Nedan får du gärna ange vad vagnen kan ha utsatts för utöver det formuläret beskriver.
(Ex. Någon har skjutit fotbollar mot vagnen. Barnen klättrar in och ut ur vagnen själva. Vagnen välter i blåst. Vagnen har tappats nedför trappa. Vagnen blev påkörd av cykel…)

Appendix C User test form, urban

Test av barnvagn

Undersökning av statiska och dynamiska belastningar på en barnvagn.

Bakgrund

Hej!

Jag är en civilingenjörsstudent som för närvarande genomför ett examensarbete på Thule Sweden om barnvagnar. Arbetet handlar om att kartlägga vilka statiska och dynamiska belastningar som kan förekomma på en barnvagn under exempelvis en promenad. Arbetet kommer förhoppningsvis leda till en större förståelse för hur tålig en vagn måste vara för att uppfylla användares behov. Den insamlade datan kan komma att användas av Thule för att främja deras utveckling av framtida produkter. I rapporter och redovisningar kommer era svar att behandlas anonymt. Undersökningen är frivillig.

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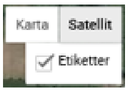
Nedan följer 3 olika delar som ni gärna får besvara så noggrant ni kan för att hjälpa mig med min kartläggning. Den första delen kräver tillgång till internet och kan ta lite tid bl.a. beroende på hur ni har använt er barnvagn. Den är utformad på ett sätt så att ni ska slippa göra så mycket som möjligt av mitt arbete. Del 2–3 är intervjufrågor.

Tack för er hjälp!

Del 1 - kartlägga runda

För att effektivt kunna kartlägga vilken sorts terräng (asfalt, kullersten, grus…) barnvagnen rullar på så får ni gärna följa nedanstående instruktioner:
OBS! Rundan ska helst vara mellan **1–5 km**! (Jag kommer senare att gå rundan och notera alla underlag och hinder).

- Var vänlig gå in på hemsidan *distansen.se*. Skriv in det geografiska området där du tagit en av dina mer utmanande* rundor med barnvagn och markera ut rundan du tog efter bästa förmåga. Se till att knappen ***Satellit*** är intryckt och att ***Etiketter*** är ikryssad.



*Med utmanande runda menas rundor som orsakat en större belastning på vagnen i form av gupp/gropar, trottoarkanter, trappsteg, svårare terräng m.m.

- Använd funktionen print screen** på din dator med kartan i **fullskärmsläge**. Skicka sedan bilden till mig via mejl och ange var rundan är samt ungefär hur lång tid rundan tar att gå i genomsnitt.

**Återfinnes på PC i form av en knapp PrtSc eller PrtScrn. Bilden klistras sedan in i ett dokument eller mejl med Ctrl + V.
På Mac används ⌘ + Shift + 3. Bilden återfinnes sedan på Skrivbordet.

OBS! Om hela rundan inte får plats i en bild, skicka då två (eller flera) olika bilder med delar av rundan på varje bild. Ha kartan så inzoomad som möjligt. Tänk på att jag tydligt måste kunna se hur ni har gått för att kunna göra en ordentlig kartläggning.

Del 2 – frågor om användning

Nedanstående frågor ställs för att få reda på kompletterande information om vilka *statiska och dynamiska* belastningar barnvagnen skulle kunna utsättas för under användning. Fyll i efter bästa förmåga:

Boendeort:

Om du bor i ett våningshus, var vänlig ange så noga du kan hur många trappsteg vagnen rullas ned/uppför i huset per promenad:
(Ex. Bor på 2: a våningen, 10 trappsteg ned. Per promenad blir det 20 trappsteg med vagn)

Antal barn resp. ålder (ange vilket/vilka av barnen som sitter i vagn):

Vilken sorts vagn har du?

Varför valdes den vagnen?

Om du har barn som ej sitter i vagn, följer de med ut på promenader med vagnen?

Om ja: Hur beter de sig kring vagnen?
(Ex. Står på vagnen, kör vagnen själva…)

Använder fler än du vagnen? Vilka?

Om ja: Hur ofta använder de vagnen? Anser du att de använder den på ett sätt som utsätter vagnen för större påfrestningar än vid eget användande? (Ge gärna exempel).

Finns det tillfällen då vagnen känts osäker? Varför?

Har det någonsin uppkommit skador på vagnen? Vilka och varför?

Har du någonsin varit tvungen att reparera vagnen? Varför?

Del 3 – egna kommentarer

Nedan får du gärna ange vad vagnen kan ha utsatts för utöver det formuläret beskriver.
(Ex. Någon har skjutit fotbollar mot vagnen. Barnen klättrar in och ut ur vagnen själva. Vagnen välter i blåst. Vagnen har tappats nedför trappa. Vagnen blev påkörd av cykel…)

Appendix D FFT and Acceleration

Here is a summary and a discussion of all the graphs produced during researching an appropriate method to compare Track 1/2 and the IrregularST.

D.1 Acceleration

D.1.1 Configuration 1

In Figure D.1, D.2 and D.3 are the filtered (0.5-50 Hz) and unfiltered accelerations from all sensors. All graphs represent configuration 1.

From the figures it is seen that the filter 0.5-50 Hz affected all the plots similarly: the overall shape stayed the same while peaks were lowered.

Track 1 is mostly lower than IrregularST with a few higher peaks. Track 2 only has a few peaks higher than the peaks in IrregularST in the z-directions. For practically all plots, the z-directions has the highest accelerations. The acceleration in the left back wheel in the y-direction is affected the most by the filter in all plots. When the Tracks' plots are filtered, their peaks' value often come closer to the peak value of the IrregularST. In the x-directions on IrregularST there is almost no negative acceleration.

In eventual future testing it seems the z-directions are the most interesting to measure since they have the highest accelerations. The y-direction on left back wheel is the least interesting since it seems to consist of mostly noise.

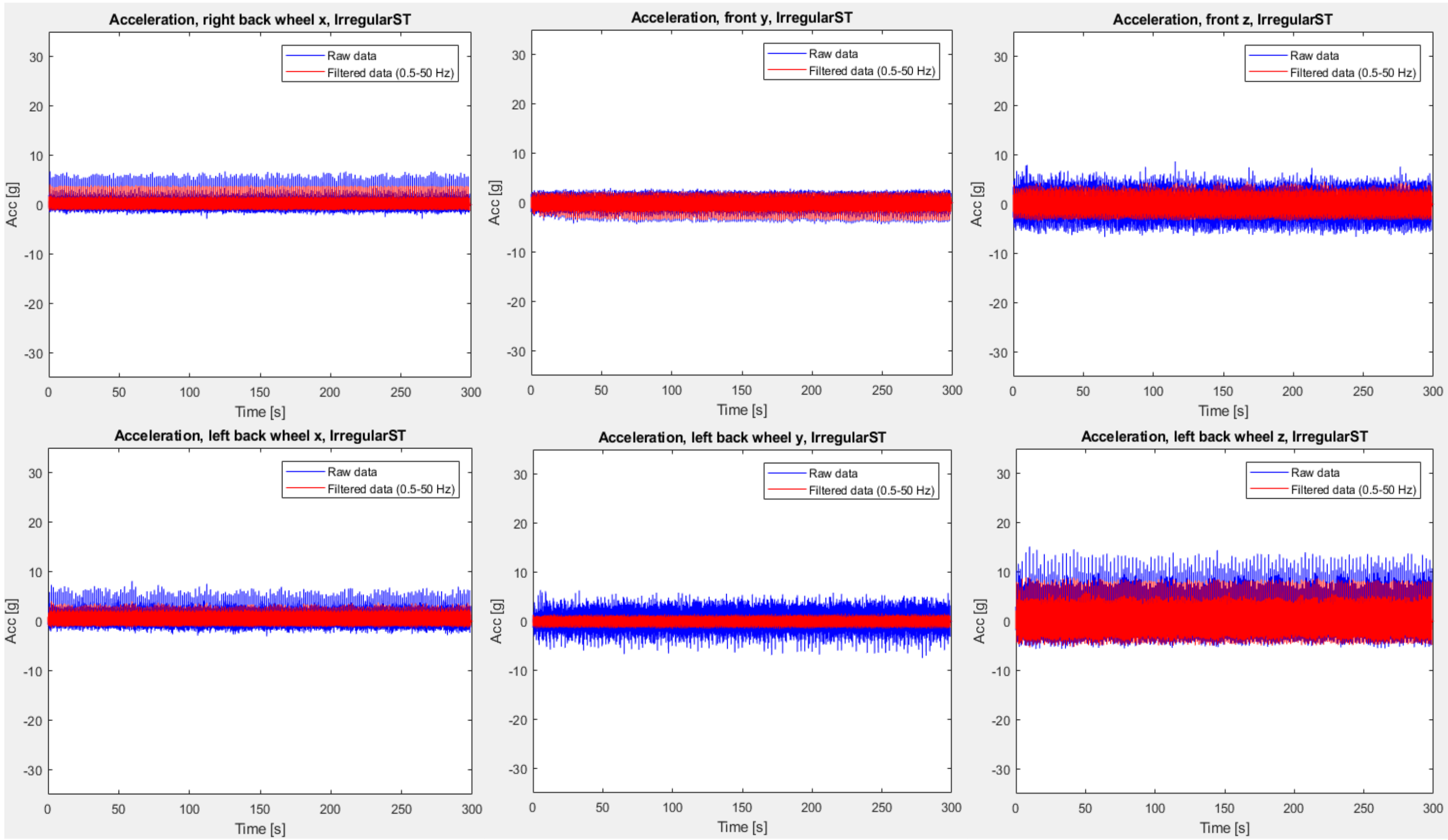


Figure D.1 - Filtered (red) and unfiltered (blue) accelerations on IrregularST, configuration 1.

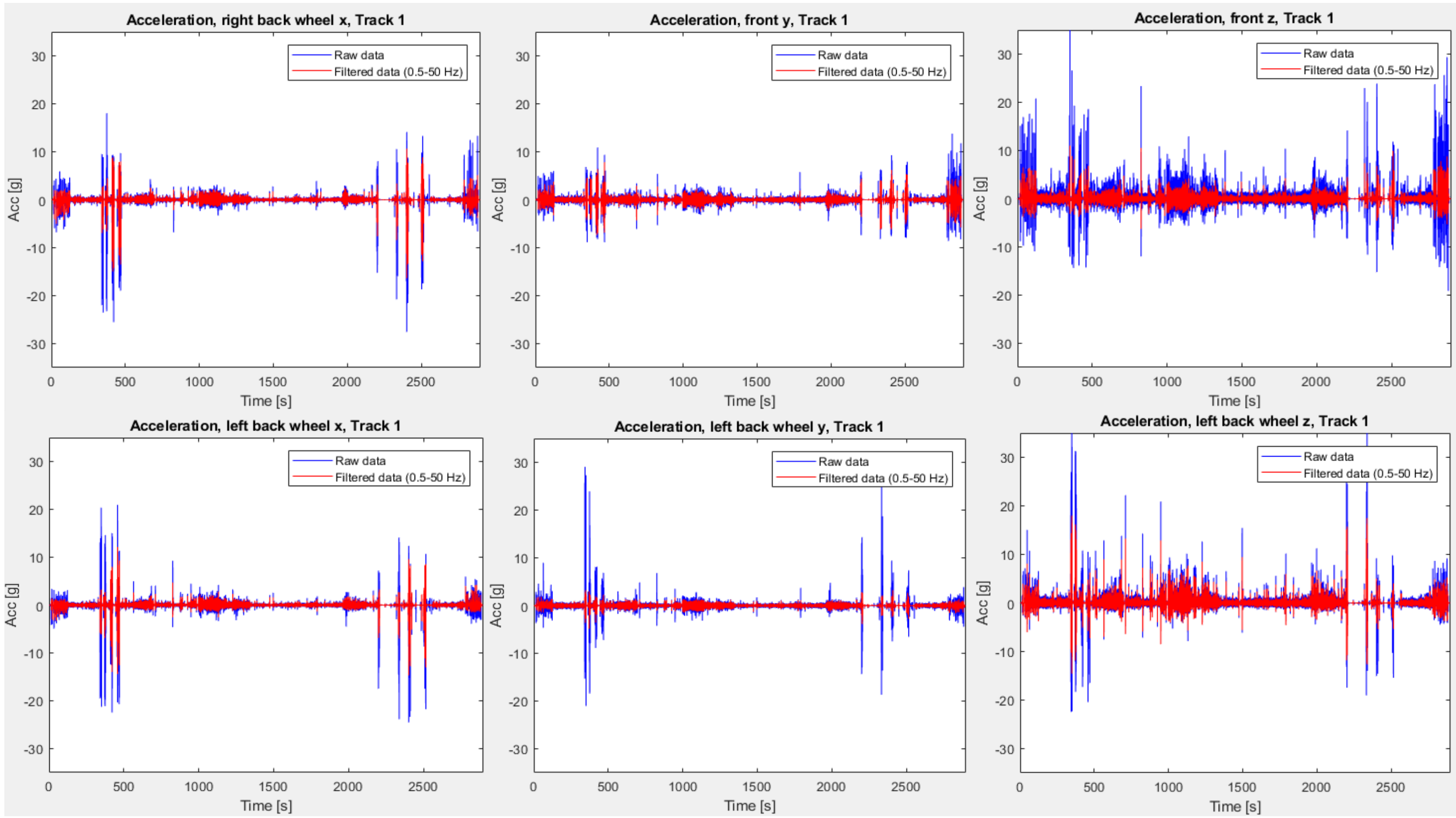


Figure D.2 - Filtered (red) and unfiltered (blue) accelerations on Track 1, configuration 1.

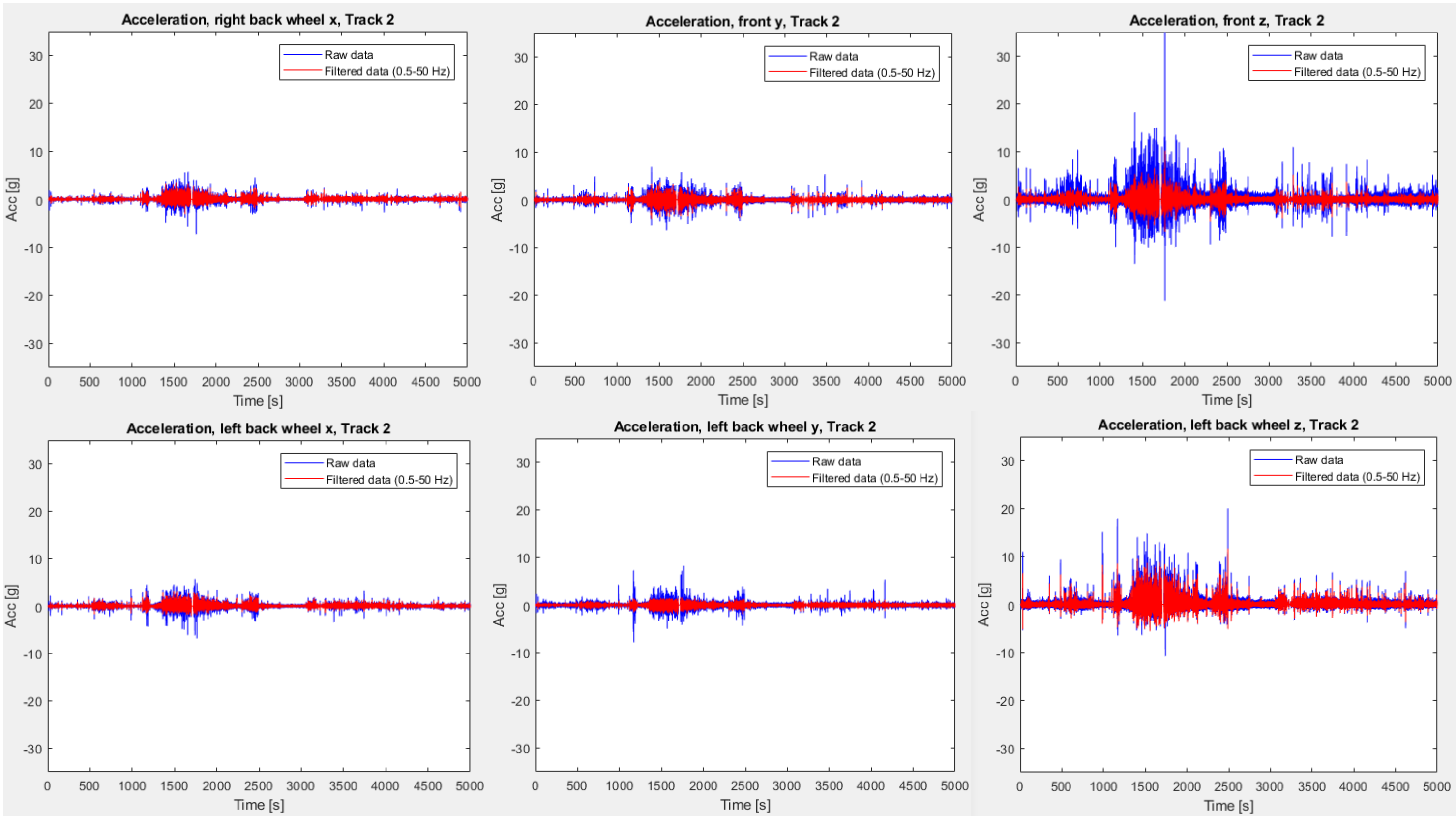


Figure D.3 - Filtered (red) and unfiltered (blue) accelerations on Track 2, configuration 1.

D.1.2 Configuration 2

In Figure D.4, D.5 and D.6 are the filtered (0.5-50 Hz) and unfiltered acceleration from all sensors in configuration 2.

In the x-direction on the mass in IrregularST there is an abnormal pattern round 150 seconds in. This hasn't been seen on any other plot which is why this can be considered random.

The filtering doesn't affect any of the plots substantially. All plots have both positive and negative acceleration. IrregularST has similar maximal acceleration in all directions, around 0.8g and -0.8g, which is close to the higher peaks of Track 2. The highest peaks of Track 1 are more than twice as high. While IrregularST show lowest acceleration in y-direction, Track 1 has its highest acceleration in that direction.

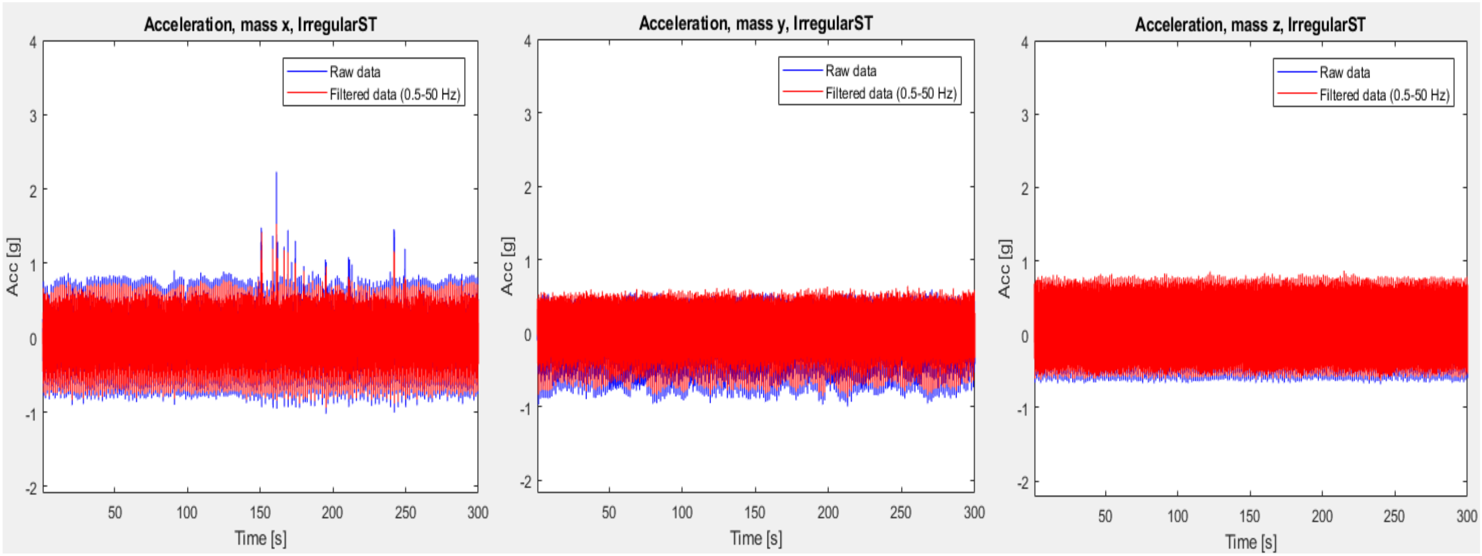


Figure D.4 – Filtered (red) and unfiltered (blue) accelerations from sensor 1, 2 and 3 on IrregularST, configuration 2.

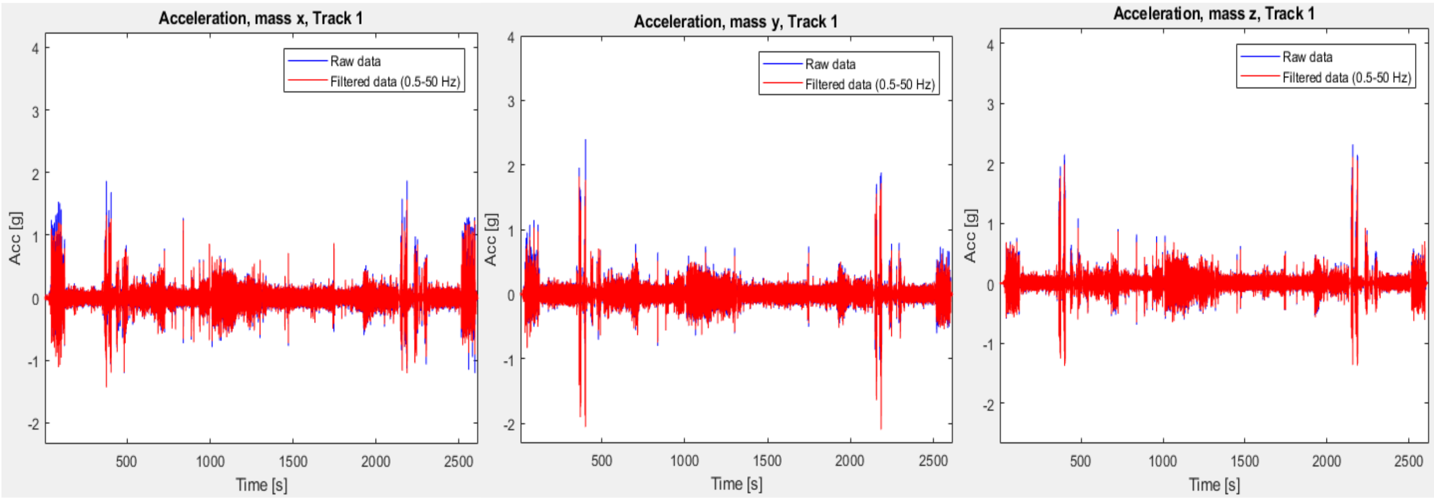


Figure D.5 – Filtered (red) and unfiltered (blue) accelerations from sensor 1, 2 and 3 on Track 1, configuration 2.

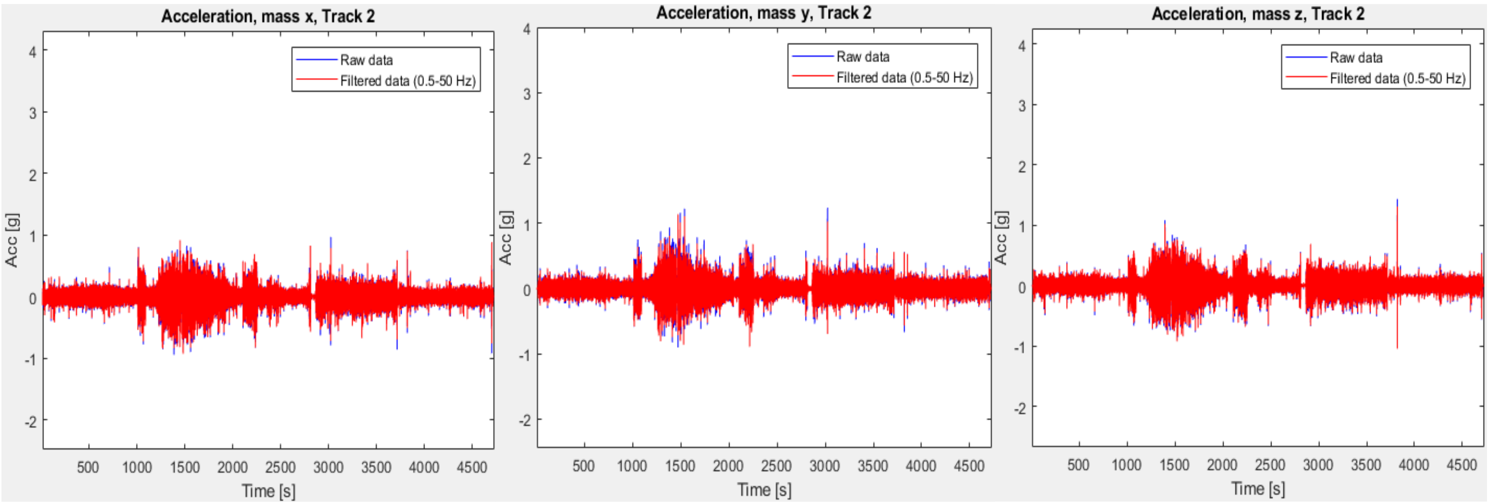


Figure D.6 – Filtered (red) and unfiltered (blue) accelerations from sensor 1, 2 and 3 on Track 2, configuration 2.

D.2 FFT

D.2.1 Configuration 1

In Figure D.7, D.8 and D.9 all FFT graphs from configuration 1 can be found.

The IrregularST shows mostly dominant frequencies around 1-25 Hz. In z-direction on left back wheel it shows dominant frequencies around 1-50 Hz. The FFT for the left back wheel in y-direction doesn’t level out as the other graphs. This could indicate that a lot of high frequencies under a short period of time occurs there.

Track 1 has no distinct dominant frequency span. In the z-direction on the front there seems to be interesting frequencies well over 100 Hz. For the y-direction on left back wheel there is a peak around 190 Hz. This matches with the noise for the corresponding plot in IrregularST.

Track 2 also has no clear frequency span, with the front in z-direction showing frequencies over 100 Hz. Once again, y-direction on left back wheel has a peak near 190 Hz. Perhaps this is a normal frequency occurring near that sensor, or sound waves occurring in the stroller body. It won’t have much effect on the stroller though, since very high frequencies won’t lead to any displacement of the stroller wheels.

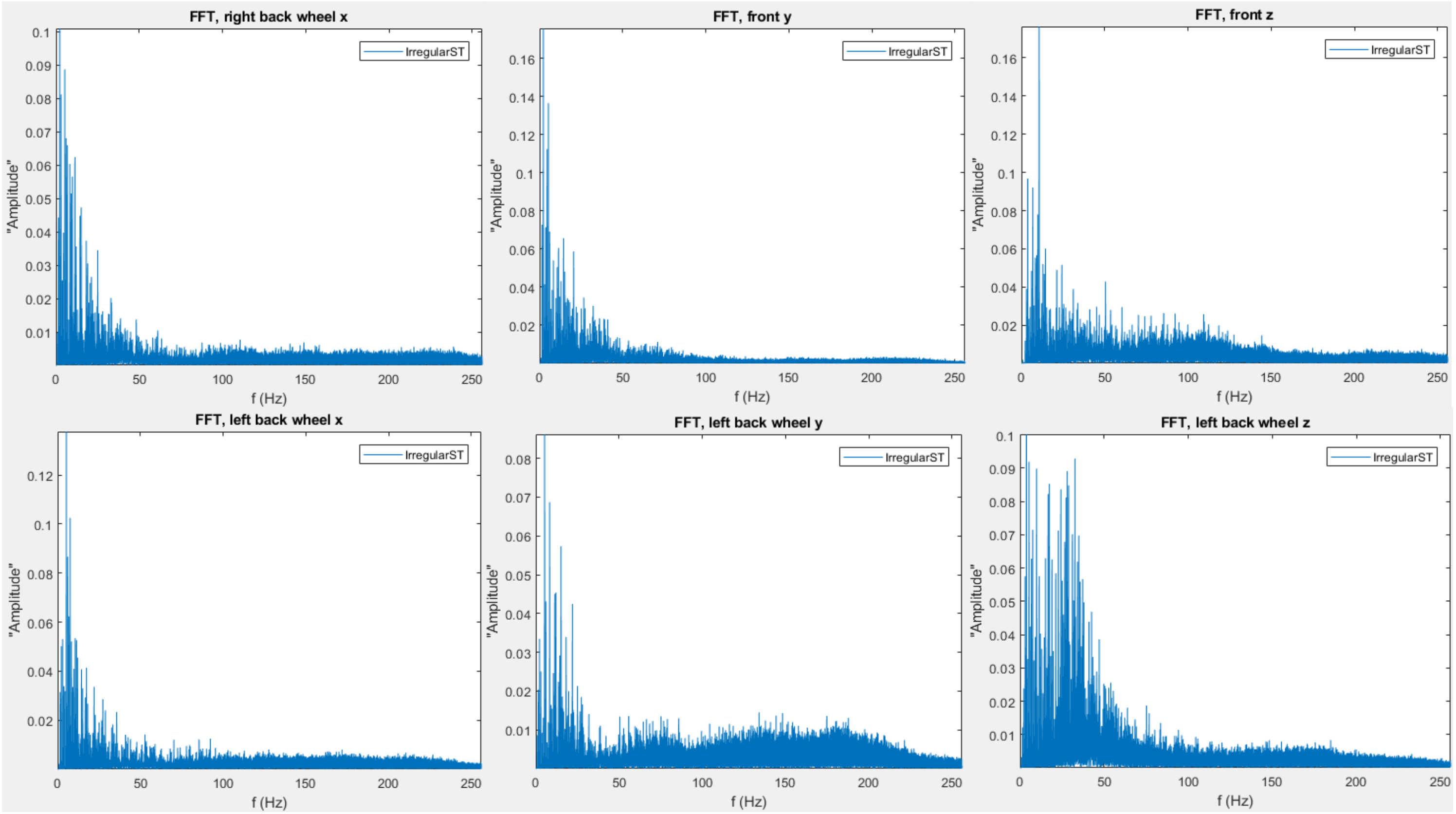


Figure D.7 - FFT from all sensors on IrregularST, configuration 1.

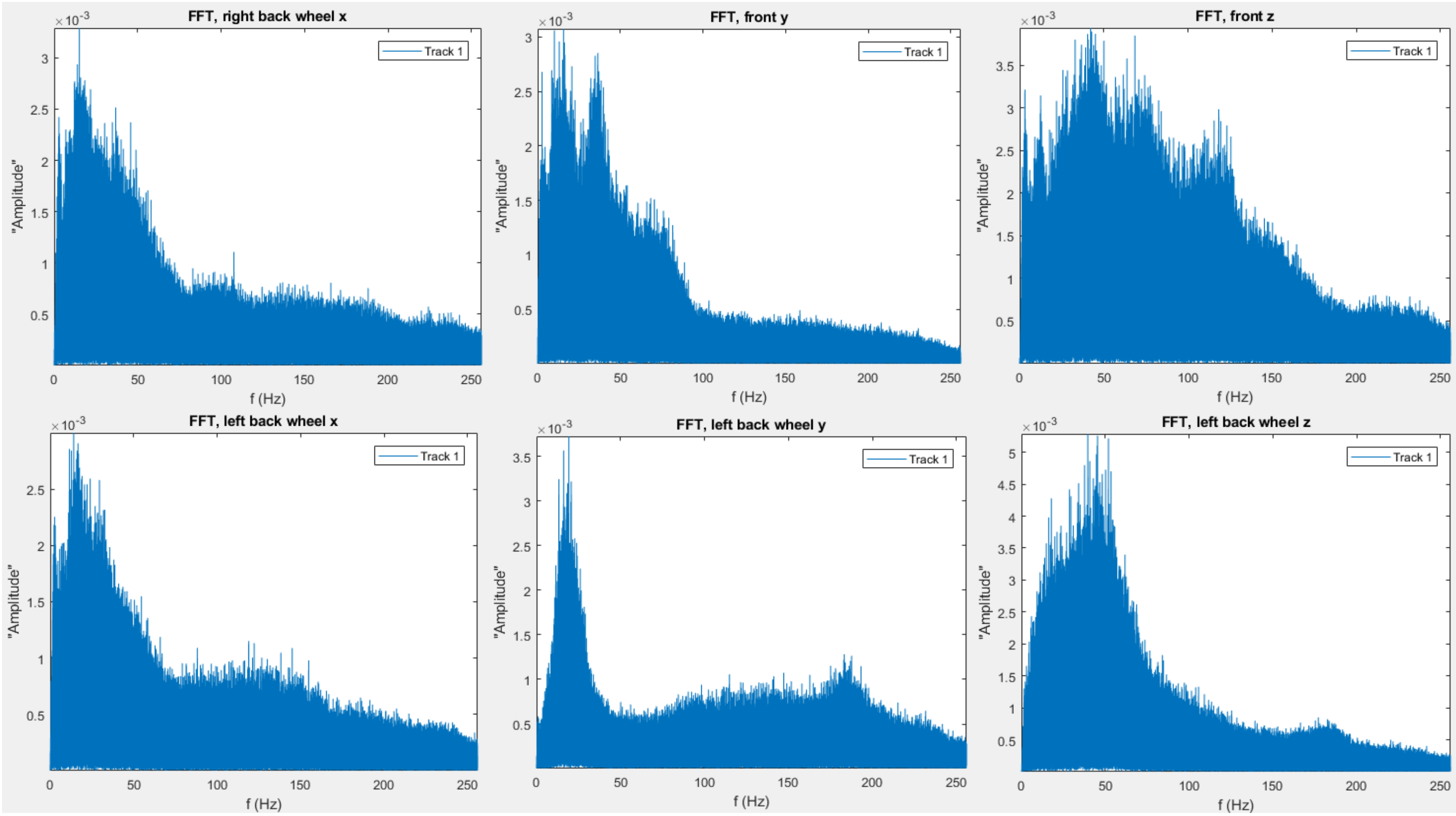


Figure D.8 - FFT from all sensors on Track 1, configuration 1.

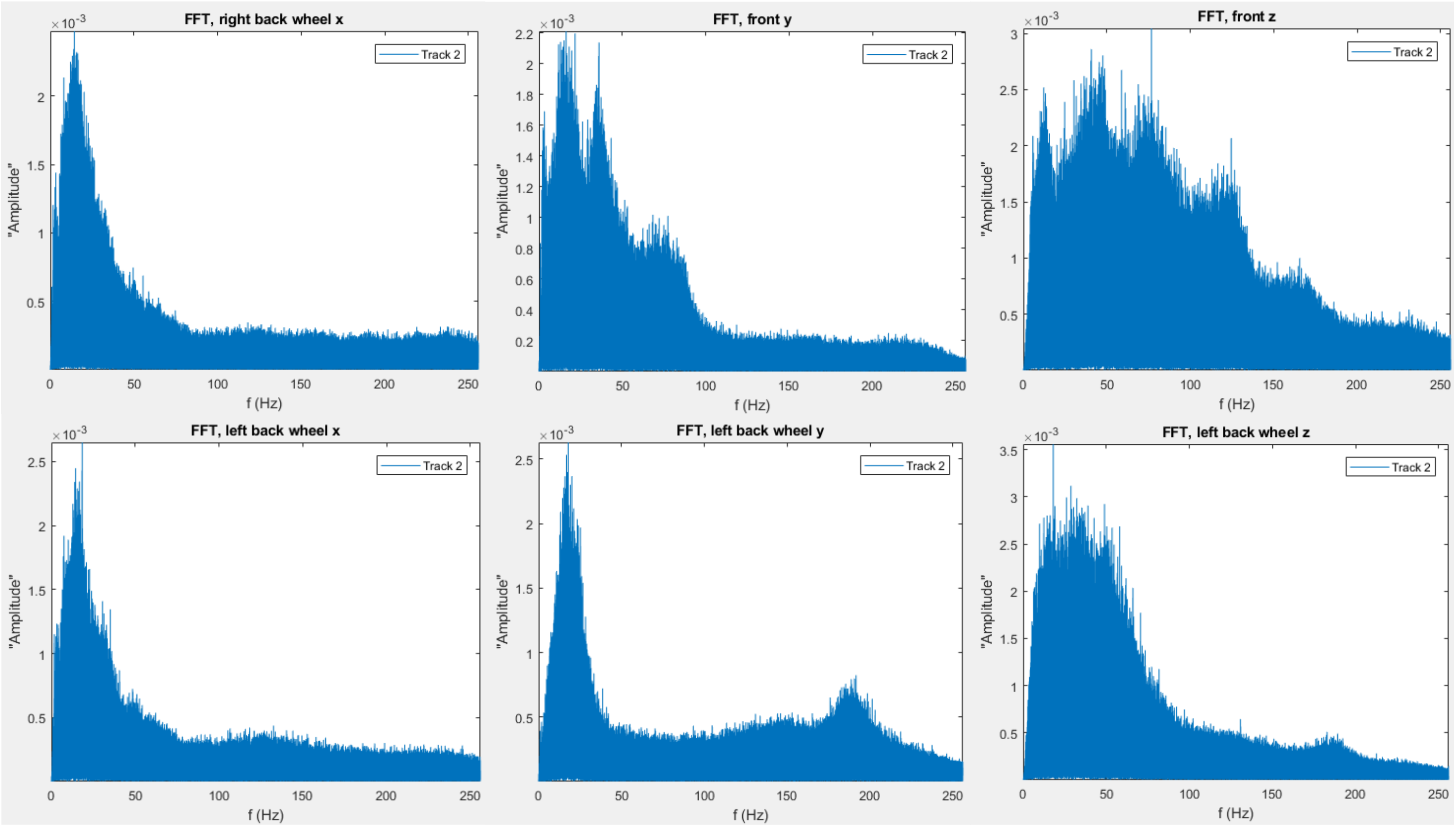


Figure D.9 - FFT from all sensors on Track2, configuration 1.

D.2.2 Configuration 2

In Figure D.10, D.11 and D.12 the FFT graphs from configuration 2 can be found.

IrregularST, Track 1 and Track 2 all seem to have dominant frequencies around 1-20 Hz. There are a few differences in the overall shapes of the graphs, but in general they seem to match quite well.

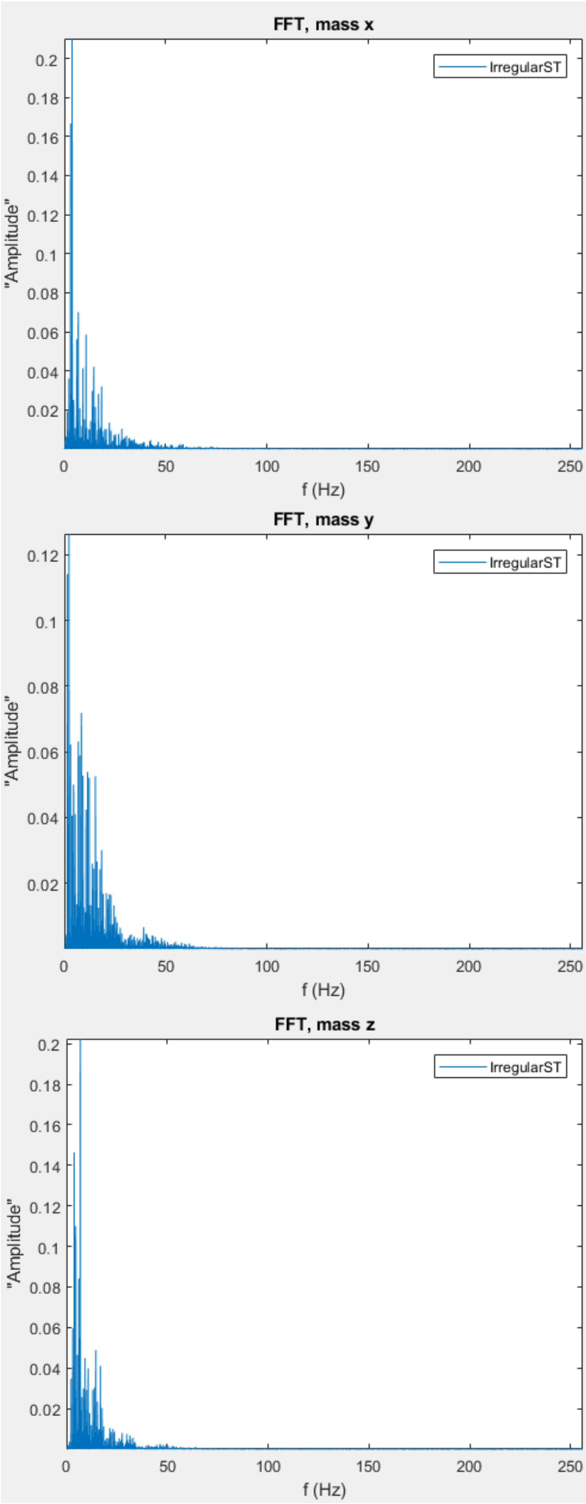


Figure D.10 - FFT from all sensors on IrregularST, configuration 2.

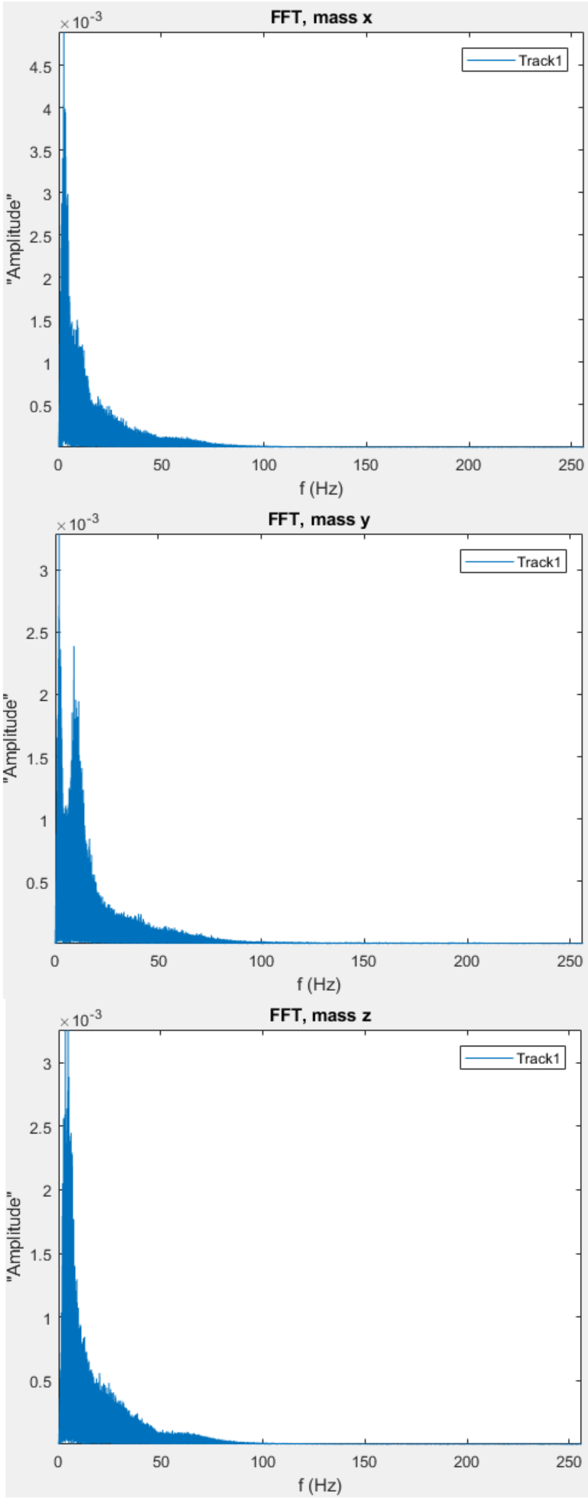


Figure D.11 - FFT from all sensors on Track 1, configuration 2.

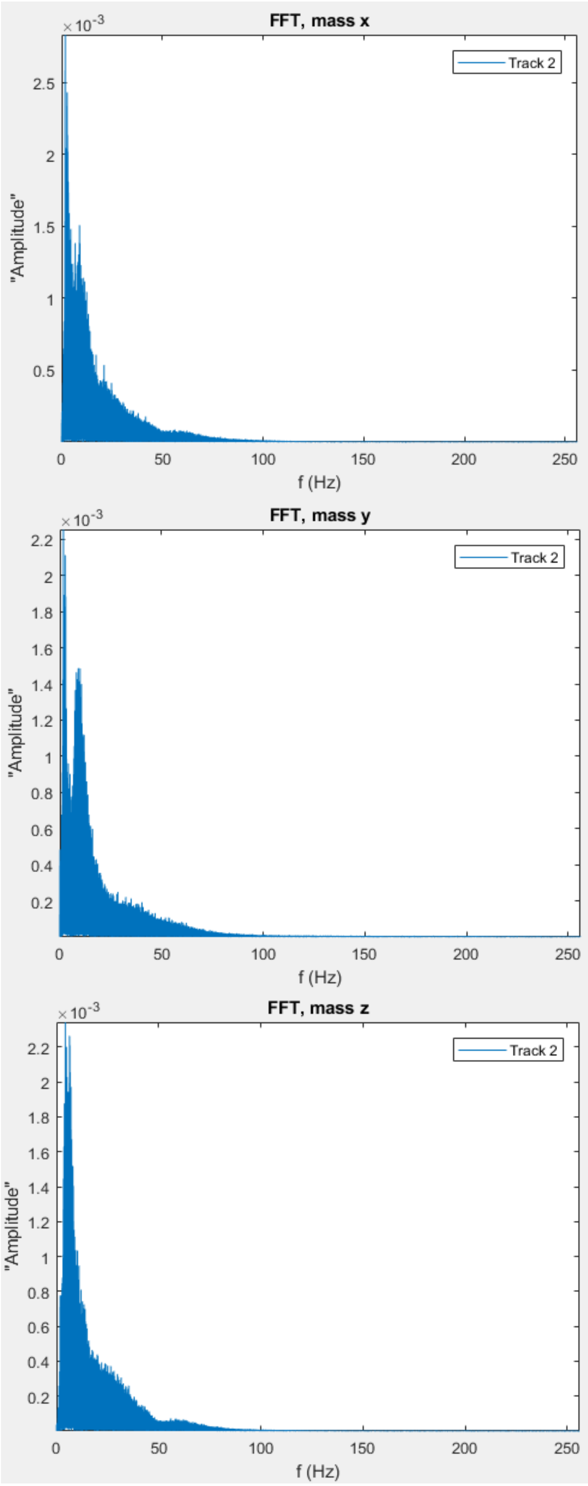


Figure D.12 - FFT from all sensors on Track 2, configuration 2.

Appendix E Work distribution and time plan

In Figure E.1 there is the original project plan made in the beginning of this master thesis. In Figure E.2 the final project plan and the outcome of that can be found.

Between the figures there are a few major differences. The first project plan in Figure E.1 has fewer and not as specified activities. When the master thesis was more specified, a new project plan was made which can be seen in Figure E.2. The biggest difference in the outcome of that plan was that testing the strollers took many more weeks than anticipated. Therefore, analyzing data couldn't be commenced until later than assumed.

In the beginning it was clear that making a customer profile wasn't the highest priority which is why it ended mid-activity. Even if it would have been of high priority, the activity should had been much longer.

The presentation was only a week delayed which is acceptable since a buffer of three weeks was planned from the start in case of problems during the project. This turned out to be true, so the buffer served its purpose.

E.1 Original project plan

Figure E.1 - Original project plan.

E.2 Outcome

Projektplanerare

Välj en period som du vill markera till höger. En förklaring som beskriver diagrammet följer.

Markerad period: 17 | Planerad längd | Faktisk start | % klart | Faktisk (utöver planerad)

AKTIVITET	PLANERAD START	PLANERAD LÄNGD	FAKTISK START	FAKTISK LÄNGD	PROCENT KLART
Rapport	1	20	1	17	100%
Litteraturstudier grund	1	4	1	3	100%
Kartläggning av kunder	2	10	2	5	100%
Testa testutrustning - allmänt	3	1	3	1	100%
Testa testutrustning - accelerometrar	5	1	5	1	100%
Testa testutrustning 3 - definiera mätpunkter	7	1	8	1	100%
Testa testbanor - jämför med kundprofil	7	1	8	1	100%
Testa barnvagnar - på testbanor	9	1	8	7	100%
Testa barnvagnar - enligt teststandard	9	1	8	7	100%
Testa barnvagnar - på specifika hinder	9	1	8	1	100%
Filtrera & tolka data	7	5	10	6	100%
Analysera standarden - är den relevant	12	4	15	2	100%
Övrigt - testa fler vagnar?	14	4	0	0	0%
Föreberedelse pres.	16	1	18	1	0%
Presentation	17	1	18	1	0%

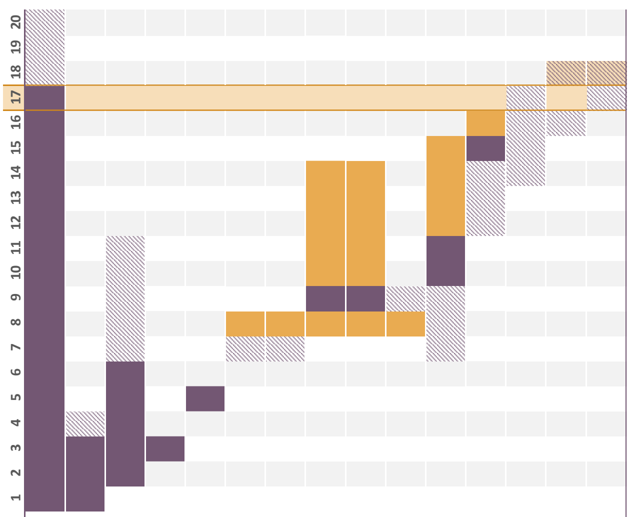


Figure E.2 – Final project plan and outcome of plan.