Fall prevention device - Signal recordings using a mm-wave radar sensor

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Abstract— **Falling is one of the most common accidents for older adults over the age of 65, with more than 70 000 cases yearly in Sweden. Today there is not a technical solution which can prevent such accidents. The development of a fall prevention device could therefore be revolutionary. A substantial database is required to develop a fall prevention device that can recognise different surroundings and give precise sensory feedback to the user when it is safe to take a step over an obstacle. Measurements on twenty volunteers were done upon request from a researcher at the faculty of Engineering at Lund University. The purpose was to expand a database with walking patterns of healthy individuals. Different scenarios were tested using a radar sensor attached to the shoe, with a connected device sitting at the ankle. The scenarios used were walking over a wood threshold, metal threshold and a water pit. This was done with the sensor on the side of the foot and at the front of the foot. In total 6 recordings on 20 volunteers were taken, making it 120 recordings all together. The measurement's purpose is to expand the database that is going to be used to develop a fall prevention device for people who have gait related issues. The recordings were transferred from the device in to labVIEW and analyzed using MATLAB. This will later be implemented in a machine learning algorithm. The goal is to find cues in the signal that an obstacle is coming before stepping over it. This way it is possible to warn ahead of time and prevent falls. This requires data collection, which our project aims to contribute with.**

I. Introduction

FALLING and getting hurt is one of the most common problems for people over the age of 65 and often leads to serious consequences such as head injuries, hip fractures and so on. [3] It can be the start of a long cycle of diseases, loss of function and in worst case death. Even if someone does not sustain an injury when falling, they might be afraid of falling again. This can make them limit their everyday activities which long term can lead to weakness, hence higher risk of falling again. The risk of falling and fall related problems increases with age. [1] Factors that can lead to falls are many, including age related system impairment, which is involved in maintaining balance and stability. [5] Other factors include certain disorders or medications used, loss of muscle, osteoporosis. Multitasking can also lead to older adults falling, for example talking while walking. Rushing to get somewhere such as the bathroom or to pick up a ringing phone can also lead to falling. This way one can miss environmental hazards, which significantly increases the risk of falling. A healthy individual is aware of the position of their feet, however this ability often degrades with age or due to certain illnesses as mentioned. In this report a healthy individuals refers to someone who has no gait related issues. The obstruction of ones walking pattern as we age can be caused by different factors and results in slowing of gait speed, symmetry, loss of smoothness as well as synchrony of body movement. As we get older the bones in our body become more brittle and are therefore more prone to fractures. High mineral content increases ultimate strength of bone, but it makes bone more brittle, therefore susceptible to fracture. As people age, bone mineral content usually remains high but loss of collagen content makes the bone brittle. Besides decreasing one's quality of life, it costs society a significant amount of money each year. Every year in Sweden about 70 000 people suffer from fall accidents, from which about 76% are adults over the age of 65. It costs approximately 16.8 billion Swedish crowns each year to care for these elderly patients who have suffered from fall related incidents. [8] The cost is expected to rise if no preventative measures are taken. [7] On the market today there exist non technical preventive solutions for example cushions which can be worn around the hips, handlebars, no slip socks, walkers and rollers. [6] The technical solutions that exist are often there to help after the fall has happened. There are security sensors that can detect falls through advanced algorithms, pocket devices that can call for help with the push of a button, wearable devices with fall detection or home monitoring systems with sensors that can detect falls. Although these are helpful they do not do anything to prevent the fall, there is a need for an updated preventive solution which this project aims to contribute to. [4] Physical therapy is another common method in fall prevention, this will still be important in addition to this fall prevention device.

A. Aim

The aim of the project is to contribute to the improvement of life quality and the safety of people affected by gait related issues. This will be done by collecting data from different everyday scenarios, where people who have trouble with gait related issues often fall. As mentioned, this issue often affects everyday life of older adults and today there is limited technical preventative methods, therefore our study aims to contribute further to developing the device that will prevent falling. This will be achieved through signal recordings, analysis of different walking patterns and later on machine learning. The data is collected to understand how people with a normal walking pattern orient their feet according to their

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surroundings and if there are any warning signs that can be seen in the radar signals ahead of an object. Three different scenarios were tested, mimicking a wooden door threshold, a metal threshold and a water puddle. Every scenario were replicated, first with the sensor on the side of the foot, then with the sensor on the front of the foot, making it six tests in total, lasting for five minuets each. The tests were done on twenty volunteers to be able to gain a general knowledge about how a healthy individual walks.

B. Thesis

This study will investigate how a sensor can effectively detect different obstacles and analyze the resulting signal changes, to help develop a fall prevention device. By recording and collecting data from healthy volunteers in various everyday scenarios where individuals with gait-related issues are prone to falling, this research seeks to contribute to the development of a preventive device. The focus is on understanding if and how the device detects obstacles and interprets signal changes, ultimately aiming to improve the safety and quality of life for individuals affected by gait related issues.

C. Agenda

The project is divided into three main parts: developing a testing protocol, conducting tests on twenty volunteers, and analyzing the data. First, the methods will be described, followed by the presentation of the results. After this, the discussion section will follow, where the results are examined and any potential sources of error will be addressed. This section will also include discussions on sustainability and ethics. The final part will present a conclusion that answers the thesis.

II. Method

A. Materials

The first step of the project involved an introductory meeting with the supervisor, during which the device and the programs used for recording and interpreting signal data were introduced. During this meeting, expectations, materials, and ideas were presented. Additionally, a previous experiment related to the project were discussed and briefly tested to demonstrate how the device functions and how the testing goes about.

Here is a list of the materials:

- Computer programs labVIEW and matlab
- Acconeer 112 XM sensor
- 3D-printed case to hold the sensor
- 3D-printed device to hold circuit board
- Micro processor
- Velcro band
- Two reference electrodes
- Computer, lenovo ThinkPad
- Surgical tape
- Micro-USB cable
- Serial communication cable
- Self adhesive aliminium foil

Figure 1. Acconeer 112 XM sensor

- Wood threshold
- Metal threshold
- Plastic lid
- Water

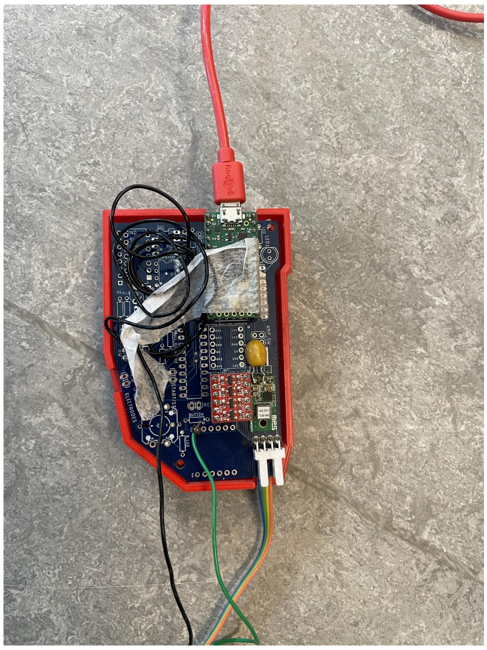

Figure 2. Circuit board

B. Description of materials

The red 3D-printed device holds a circuit board, seen in figure 2. The board contains a power regulator for the sensor and the microprocessor that reads the radar sensors data and transfers it to the computer. The bottom part it is connected via a cable to an orange 3D printed case that houses the sensor. The sensor in its case, seen in figure 3, is placed on the shoe and registers the surroundings between a 2 cm to 32 cm distance. The sensor emits electromagnetic waves, with millimeter-long wavelengths. Sending electromagnetic pulses at regular intervals with a frequency of 60 GHz. [2] The radar system listens for the echoes or reflections of these pulses bouncing off objects in its set range. The circuit board sends the signals from the sensor to a computer via a micro-USB cable connected to the top of the circuit board. The signals are shown in labVIEW in close to real time.

Figure 3. The sensor in its 3D printed case

The 3D printed case where the sensor sits is plastered in a self adhesive aluminium foil to minimize static electricity. Two electrodes are connected to the circuit board, one is plastered with foil and attached to the orange 3D printed case that holds the sensor, while the other is placed in contact with skin.

C. Measurements

To do a signal recording, the 3D-printed part with the circuit board needed to be fastened to the ankle with the velcro band, see figure 4. One of the electrodes had to be in contact with skin and was either placed inside the sock or with a small piece of tape.

Figure 4. Sensor placed on the side of the foot

Figure 5. Sensor placed on the front of the foot

The sensors 3D-printed case was attached to the shoe using its hooks, shown in figure 4 and figure 5. The device was connected to a computer via a micro-USB cable. When ready a yellow light on the device lights up, to indicate that a stable connection is established. If the connection is unstable, a smaller red light further up lights up. To start the recording the white arrow at the top of the screen in labVEIW was clicked, and to stop the STOP button in labVIEW was clicked, see figure 6.

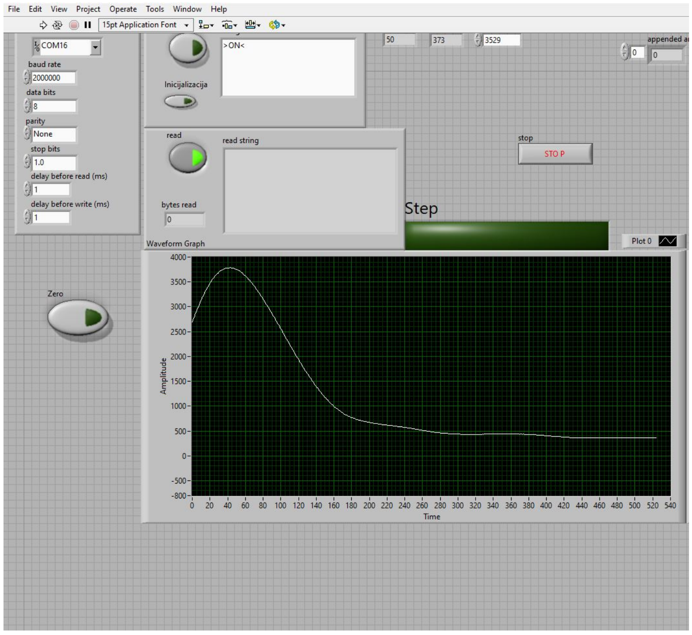

Figure 6. LabVIEW

The volunteers walked with the computer in their hands and clicked the Enter button when taking a step over the object. They held down the Enter button when turning around to go back over the object, as seen in figure 7.

Figure 7. Volunteer walking over the wood threshold

This was done in order to eliminate misinterpretation of polluted signal recordings as the different obstacles in the tests, for example from the walls when turning. This made it clear to see the instances in the recording when the participant walked over for example the threshold, in the analysis later. The smaller yellow marks indicate a step, the broader yellow marks indicate a turn, see figure 8.

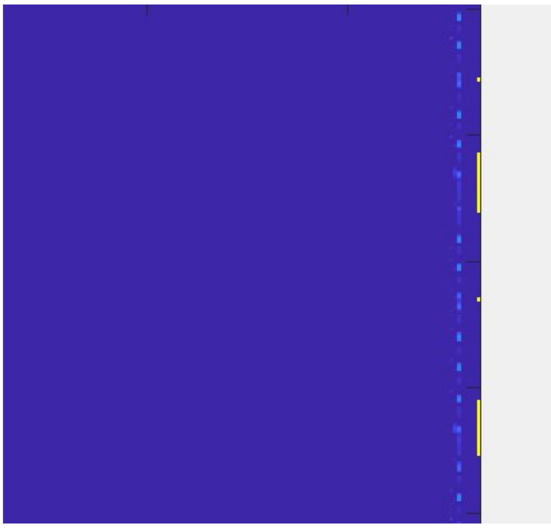

Figure 8. Yellow marks to indicate when the Enter button was pressed

When the recording was stopped in labVIEW it automatically saved as an lvm file on the computer. A document was used to keep track of file names and what volunteer did the test, as well as which object the volunteer was walking over. It was decided to conduct 2 to 3 different tests. The decision landed on a water pit and door threshold, as they were considered as common types of obstacles one can meet in everyday life. In addition to that they could be replicated in the lab. All the volunteers were given four digit anonymous codes, they were informed about the study via a written document and signed before testing began.

D. *Protocol*

A small scale pilot study was conducted to form a protocol for the main data collection. During the protocol formation, numerous tests were done with two scenarios: the threshold and water pit. First the threshold was tested by walking in and out of rooms and around the corridor, the button was pressed when crossing the threshold. The tests were performed at varying paces, with different focuses and had different lengths. The length of the recordings ranged from 3 and 10 minutes. Ultimately it was determined that 5 minute recordings were best. For some tests the emphasis was solely to walk over thresholds with minimal movement around the corridor, in other tests the focus was to walk around in the corridor between each step over the threshold. To create an indoor water pit, first it was attempted to pour water directly onto the floor, this was not a good solution. Therefore a plastic container lid, see figure 9, was filled with water, as a more suitable solution.

Figure 9. Water pit, wood threshold, metal threshold

After gathering all the recordings they were plotted and analyzed in MATLAB. The tests revealed some signal pollution from the surroundings, the pollution was created by chairs, tables etc. Therefore it was decided to test again with a different approach. Two new thresholds, one made of wood and the other of metal, were constructed to be placed in various locations. After testing both the metal and the wooden threshold is was decided to include both in the recordings moving forward. The water pit, housed in a plastic lid, could also be relocated as needed. It was decided that the tests should take place in a spacious corridor, about 2 meters wide, for minimal polluted recordings. The participants were instructed to walk over the threshold or water pit, and press the Enter button when the foot was directly over the obstacle. Then they were going to take a few steps and turn around to walk back over the threshold or water pit. While turning around they would hold the Enter button pressed down, which would make it easier to see when they turned around, when the signals were plotted and analyzed in MATLAB later. The participants wore the sensor on the left foot and therefore had to walk over the obstacles with their left foot every time. It was important that all the tests were done exactly the same way, therefore everything was explained thoroughly before the recordings began.

E. Data collection and qualitative analysis

After forming the protocol, a data collection on volunteers began. The volunteers were from Lunds faculty of engineering. There was no predefined selection criteria based on gender or age, the only requirement was that the participants had no gait related issues. The age group turned out to be limited to 23±3. The recordings were conducted on both male and female students, of which 4 were males and 16 were females. After recording data from the participant, the lvm files that were saved from labVIEW were imported to MATLAB. To import the files an lvm import pack from MATLAB was downloaded. Then the files could be plotted by first saving the data in a variable, then plotting it using the image plot alternative in MATLAB. See figure 10 for MATLAB code. It was challenging to see at what point the Enter button had been pressed down during the recordings, therefore yellow markers were added to the plot to make it easy to see when the Enter button was pressed and how long it was pressed. The longer it was pressed the longer the yellow mark appeared, see figure 8.

```
%Importing file
d = lvm_import(['test_136.lvm']);
%%
%Plotting radar signal
ppp=d.Segment1.data;
tt= (ppp-ppp(10,:))/5;
tt(:,end)=tt(:,end-1)*4000;

figure;
image(tt);
xlabel('Samples (20 per second)')
ylabel('Distance (cm)')

%Step diagram
plot(tt(:,end))
```

Figure 10. MATLAB code example

To get a better view and understanding of the radar signals, the colour scheme of the radar signals were adjusted numerous times in MATLAB, to achieve a clear view of the signal. The steps were also plotted using the line plot option. This was mainly done to see how many steps were taken, and double check that the yellow marks on the radar signal plots turned out correct. The recordings were compared and analyzed to try and find common factors and see signal trends.

III. Results

The project consisted of 20 volunteers doing a total of 120 recordings, of which 18 of the volunteers were able to complete their recordings. 13 of the recordings could be done in one session without the sensor stopping. It was only possible to reschedule to complete recordings with 5 of the 7 volunteers who were affected by the difficulties with the device. This has led to 2 recordings not being complete because of issues with the device and lack of time for rescheduling.

In figure 11 and 12 one of the water pit recordings can be seen. When walking over the water pit, the signal amplitude increases and the width is greater. With the sensor on the side of the foot, see figure 11, some activity is observed before the participants foot is directly over the water. When the sensor was placed at the front of the foot, see figure 12, significantly more activity was detected.

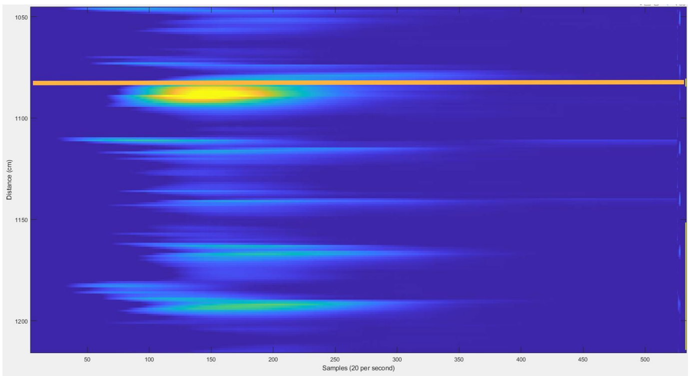

Figure 11. Zoomed in radar signals from water pit recording with the sensor on the side of the foot

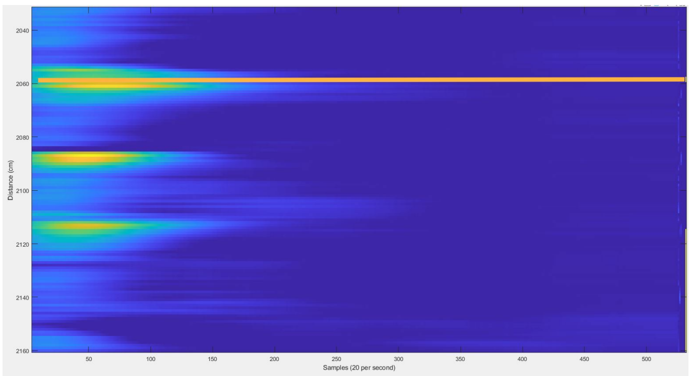

Figure 12. Zoomed in radar signals from water pit recording with the sensor on the front of the foot

In recordings involving the wood threshold with the sensor placed at the front of the foot, see figure 14, activity was detected before stepping over the threshold, this could be seen when the sensor was placed on the side of the foot as well. Signal amplitudes were larger and wider when stepping over the threshold compared to steps taken before and after, this can especially be seen in the recordings with the sensor on the side of the foot, although this can be said about the recording with the sensor on the front of the foot as well the increase in amplitude size were not as big. The signal amplitude shows more intensity with the sensor on the side of the foot, as seen in figure 13, compared to when the sensor is on the front of the foot.

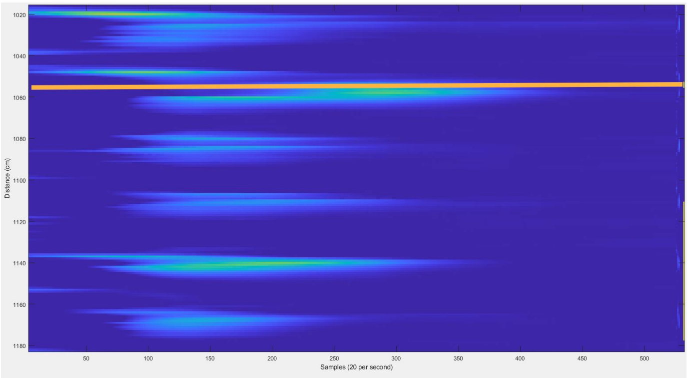

Figure 13. Zoomed in radar signals from wood threshold recording with the sensor on the side of the foot

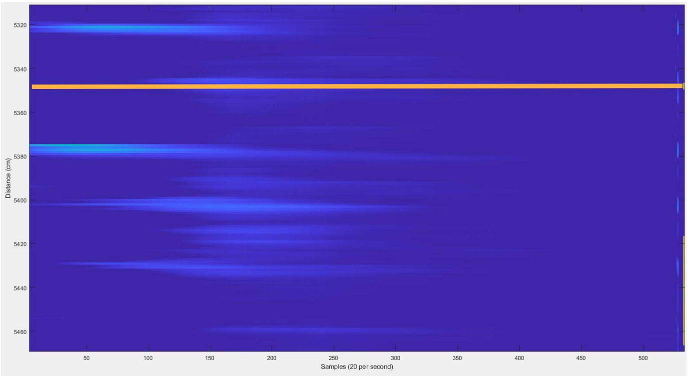

Figure 14. Zoomed in radar signals from wood threshold recording with the sensor on the front of the foot

Recordings of the metal threshold showed similarities to the wood threshold recordings, with amplitude and width increasing, detection of the threshold before stepping over, as well as the signal being more intense with the sensor on the side of the foot. However, signals from the metal threshold, see figure 15 and 16, were visibly more intense than the wood threshold.

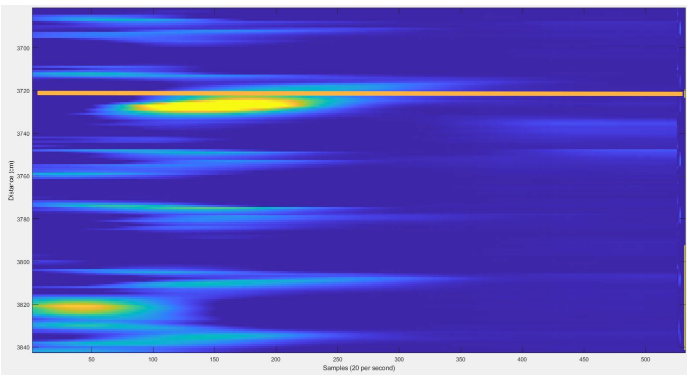

Figure 15. Zoomed in radar signals from metal threshold recording with the sensor on the side of the foot

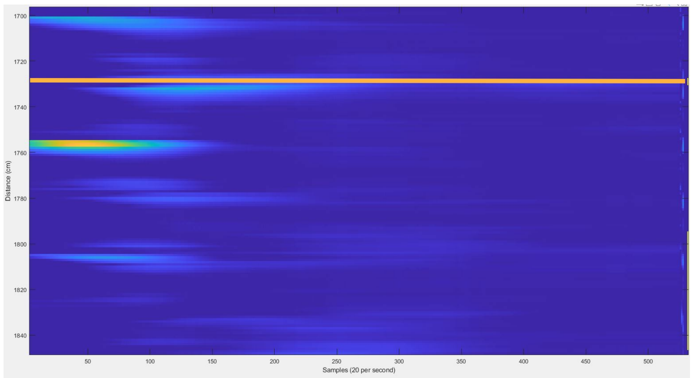

Figure 16. Zoomed in radar signals from metal threshold recording with the sensor on the front of the foot

IV. Discussion

The figures 11 to 16 represent a complete recording of the 6 different scenarios of one of the participants. The signal amplitude and width are clearly visible in the zoomed in figures, alongside instances of which the Enter button was pressed. These instances are represented by the short yellow markers on the right side of the diagrams, in addition to this an orange line has been added to clearly show when the Enter button was pressed. The longer yellow marks represent the instances where the Enter button was held pressed down when turning around.

The increased signal amplitude and width when approaching and stepping over the water threshold, see figure 11 and 12, especially with the sensor on the front of the foot, shows the devices ability to detect potential hazards early on. This was a common factor on the recordings, a couple of centimeters before the water pit some activity can be seen. The exact amount of centimeters did vary a bit, this can be due participants using different shoes and/or angling their feet differently when walking. The increased signal detection before stepping over the water pit, with the sensor on the side and especially on the front of the foot, is beneficial results for the purpose of the device, as the aim is to be able to detect and recognise the surroundings, to prevent falls. The plastic lid containing the water pit interferes minimally with the detection of the water, as plastic barely reflects the electromagnetic waves due to its low conductivity.

With the wood threshold the signal is not as intense as the water pit recordings. However, it seems the threshold can be detected before stepping over. The signal is more intense with the sensor placed on the side of the foot, this might be due to the wooden threshold being flatter and therefore not as detectable when the sensor is placed at the front of the foot. As mentioned above for the water pit recordings, the distance of witch the signal showed detection of the threshold varied a bit between the participants.

While similarities exist between recordings of the metal and wooden thresholds, when comparing the recordings with the sensor at the side and front of the foot, the signals recorded from the metal threshold are visibly more intense than the wood, as seen in figure 15 and figure 16. This difference could be due to the fact that metal is a better reflector than wood, due to its higher conductivity. How conductive a material is will determine how well it reflects back the electromagnetic waves. The width of the signal amplitudes are a bit narrower in the wood threshold recordings compared to the metal recordings, this might be due to the fact that the metal threshold is thicker than the wood threshold that was used.

A. Challenges

In the beginning as well as during the process, mainly in the testing phase, some challenges were encountered. The device would stop recording abruptly in the middle of the test. These factors were identified as causes that led to disruptions in the recordings; a cable not working and needing to be replaced, the device not working properly due to static electricity created by certain shoe soles when walking on the linoleum floors, as well as needing to restart the device for it to record properly due to a loss in connection. To restart the device the micro-USB cable had to be unplugged and plugged in again in either the circuit board or the computer. At times the recordings had to be cancelled, which lead to delays in the testing process, but also inconveniences for the volunteers. New recording sessions had to be arranged with several of the volunteers because of the device failures. This has taken a lot of planning. However, the challenges faced have been solved with the help of the project supervisor, who managed to fix the device, so the recordings could proceed as usual. The device failing has led to some positive outcomes as well, it helped with the understanding of all the parts of the device, and how they worked together. After the device was fixed the recordings went smoothly and there were no more issues with the device. Despite the initial challenges the projects expectations were met, a protocol was made, almost all recordings were finished and a qualitative analysis was done. The challenges that have appeared during the process have also been quite beneficial as they have helped develop and improve the device.

B. Limitations

A potential limitation with this study could be that the participants were only students from Lunds Faculty of Engineering, limiting the diversity of factors like age. Because of initial struggles with the sensor, part of the recordings were obstructed and couldn't be used. There was not enough time to bring back all the volunteers whose tests did not go to plan. Out of 20 participants in total, 18 of them could complete all the recordings, the remaining two only performed parts of the recordings. There might also be possible sources of error, where the participant has unintentionally pressed the Enter button at the wrong time or forgot to press, when walking over the obstacle or turning. Another limitation with this study is that participants have different ways of walking and use different shoes. Depending on the walking pattern, the electromagnetic waves hit the signal at different angles and therefore reflected back with different distances. This might have affect the signal recordings slightly.

C. Improvements

The study consisted of only 20 participants, therefore in the future one could include a larger amount of participants to get more generalized results. The study could also be done with a more equal men to women ratio, as the majority of the tests in this study were performed on women. A potential improvement on the device itself could be to adjust the sensor's measurement range which in this study was 2 cm to 32 cm. This can be beneficial to see how the distance range of the sensor can impact signal recordings. The device as of now, only has one sensor incorporated. It could be interesting to have two sensors incorporated to record signals from the front and side of the foot at the same time.

D. Sustainability and ethics

Sustainable development and ethical considerations are aspects that have been taken into consideration during the process of this study. In terms of environmental sustainability this project has contributed by for example 3D printing parts of the device, therefore eliminating unnecessary shipping from other countries, which could impact the environment through gas emissions. Additionally, the device's reusability minimizes waste. However, during the experiments, surgical tape had to be used to keep parts of the device in place. Parts of the device had to be changed through out the process; the micro-USB cable and the serial communication cable. It's believed that the study's benefits far outweighed this minimal environmental impact.

Social sustainability is a key focus, as the project aims to positively impact the lives of elders and individuals with gait-related issues. Falling and getting hurt can have serious consequences and limit ones life. Some might live in fear of falling, others might have limitations because of injuries caused by falls, in both cases it can result in lower life quality.

Economic sustainability is also an aspect this project has the potential to have a positive impact on. By reducing the numbers of falls or reducing the severity of injuries, a huge cost to healthcare can be avoided. Instead the resources can be redirected to improve other parts of society.

An ethical aspect to be raised can be the affordability of the device. Usually devices like this can be invaluable to patients. It varies a lot how different healthcare systems finance aiding tools, therefore it might not be accessible to everyone. It can depend on the varying healthcare system policies in the country one lives and individual economic circumstances.

As the study consists of volunteers, it is important that each of them has been informed of the nature of the study and how the recorded information is going to be used. In accordance with the GDPR law, personal information such as name will be handled appropriately and not shared without the participant's consent. The study is approved by the Swedish Ethical Review Authority (Approval ID 20220308201) and each participant provided informed consent prior to the experiment.

V. Conclusion

The project has resulted in useful signal recordings that are going to be used to further develop the fall prevention device. The aim with the study was to investigate how effectively the sensor can detect obstacles. From the results it can be seen that there are differences between the signals reflected, depending on the different simulated obstacles in the study.

VI. Acknowledgements

Thank you to Nebojsa Malesevic, our supervisor who has provided us with all the necessary tools and has been there in every step of the process and was always ready to help when any issue arise. A huge thank you also goes to all of our participants who voluntarily took part in our study and have been patient with the inconveniences we have had during the recording sessions.

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Picture references:

All pictures belong to the report authors.

Appendix

Appendix 1, *Radar signals from the six different types of recordings done*

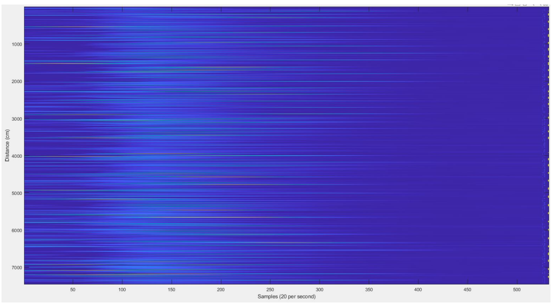

Figure 17. Radar signals: Wood threshold with sensor on the side of the foot

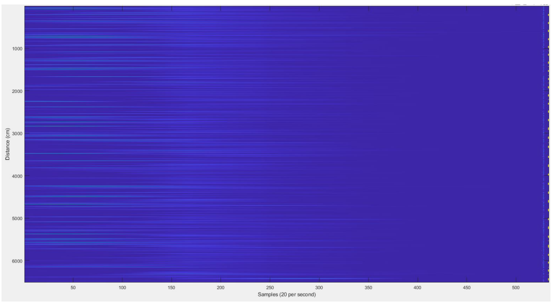

Figure 18. Radar signals: Wood threshold with sensor on the front of the foot

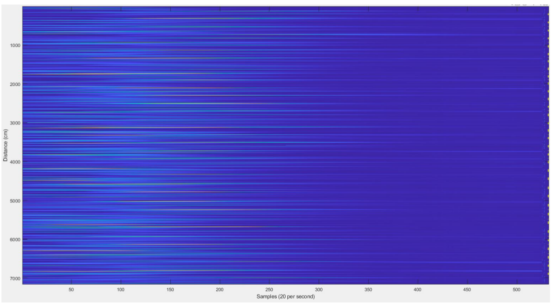

Figure 19. Radar signals: Metal threshold with sensor on the side of the foot

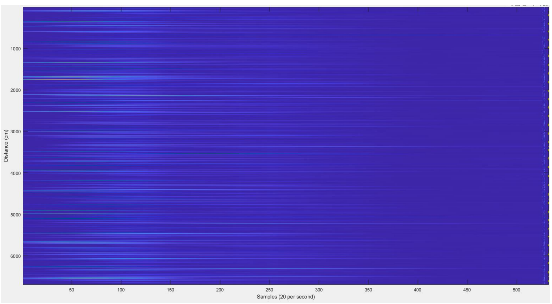

Figure 20. Radar signals: Metal threshold with sensor on the front of the foot

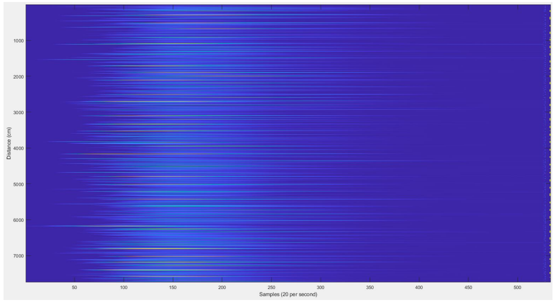

Figure 21. Radar signals: Water pit with sensor on the side of the foot

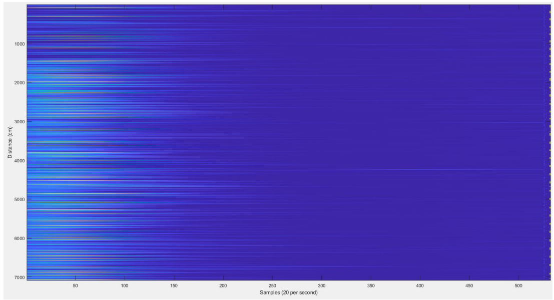

Figure 22. Radar signals: Water pit with sensor on the front of the foot

Appendix 2, *LabVIEW block diagram created by Nebojsa Malesevic*

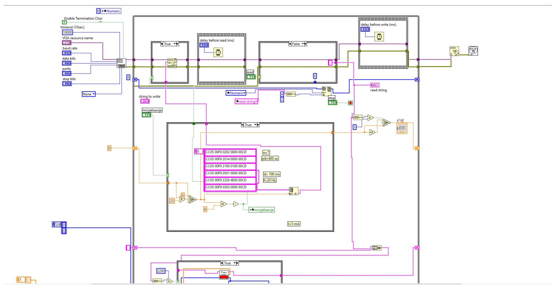

Figure 23.

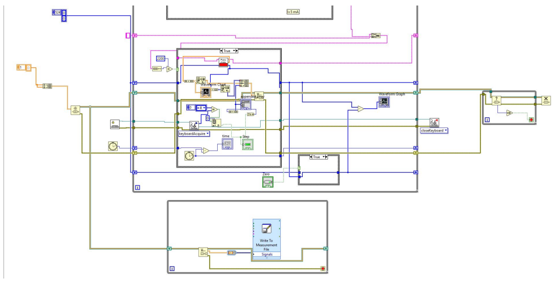

Figure 24.