University of Southern Queensland

Faculty of Health, Engineering & Sciences

The Adaption of Dynamic Shape Display Technology for use with Virtual Reality Treadmills

A dissertation submitted by

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Abstract

With the advancement in technology, there have been new technologies that enables a more immersive gaming experience for the user. Even though these new technologies offer more immersive experiences, they are still not truly immersive as there is a disconnect between the environment that the user sees in the virtual reality headset and the environment that the user is feeling under their feet. This created the motivation of this project by trying to overcome this disconnect through replicating the feel of different ground types through the use of a pin and spring system and to be able to replicate the topography of the environment through the adaption of dynamic shape technology.

Throughout this project different spring configurations were tested to investigate the viability of using springs to replicate the different ground feels. This was done through creating a test rig that displayed different spring configurations that included one spring and two spring configurations in different gauges in a single layer and three spring configurations in different gauges positioned in a dual layer. The test rig was then graded on a scale of one to five with one being the hardest feeling surface and five being the softest and was tested at different compression states (fully uncompressed, half compressed and fully compressed) to determine the feel of each compression stage. The topography test was to test the viability of the integration of the two systems through testing how well the system performed under force and no force at various speeds.

The outcome of the tests concluded that the configurations that used three springs were the most stable but also the stiffest and hence was not viable. It was decided that for the scaled prototype, the best spring to be able to replicate different ground types was a 3/8" x 5/8" gauge spring in a single layer configuration that utilised only a single spring. The topography tests concluded that the motor chosen for the prototype was not able to withstand forces being placed on the system and hence different motor and actuation methods would need to be considered. It was determined that the viability of the two systems together was acceptable as they operated independently of each other and hence did not influence each other. Integration of these systems to virtual reality treadmills should be achievable if pin size and layout, motor size and power and computational needs are considered. Further investigations are required prior to a full scale model is achievable.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses, and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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1 Introduction

Current technology is always evolving with new or improved versions being released continuously. One field that is rapidly expanding is the entertainment industry, particularly the gaming industry. A particular area of interest in the gaming industry is virtual reality as it lets users experience gaming in a way that has never been experienced before. Although virtual reality is predominantly used within the gaming industry, it has been adopted in other fields including but not limited to, the medical field, engineering field and even sales fields. This technology has been able to reach as many fields as it has as it is an immersive technology which is designed to make the user believe that they are in another environment and are able to interact in ways that they would be unable to with conventional technology. They would be able to inspect a prototype more closely than what they would be able to on a computer, to be able to practice a surgical procedure without any risks and to be able to walk through a designed building prior to construction.

Virtual reality is capable of tremendous things; however, it does have its restrictions. These restrictions are in the form of the user being limited to the space of a room or sometimes even the place where they stand or sit. These restrictions disrupt the authentic feel of virtual reality, but these have been rectified slightly with the development of virtual reality treadmills and its ability to allow the user to move around freely on a platform. Although virtual reality treadmills have overcome the movement restriction, they are unable to replicate the virtual terrain layout or the feel of the terrain displayed. It is due to this that the aim of this project is to adapt virtual reality treadmills to be able to adapt instantaneously to replicate the virtual terrain layout and terrain feel to allow users to have a more connected feeling to the virtual space they are exploring.

1.1 Project Outline

Due to the developments within the virtual reality industry there is a need to develop a more immersive experience for the user whilst using a virtual reality headset. This identified the need to allow the user of virtual reality headsets to feel like they were actually walking on the terrain that was displayed in the virtual reality headset including the feel or hardness of the ground that the user is walking on. How this will be achieved is outlined in section 1.2.

1.2 Aims & Research Objectives

With virtual reality making strides towards being a fully immersive experience, there is a need for the ability to be able to replicate the look and feel of the virtual environment displayed on the surface that the user is physically walking on. The aim of this project is to be able to achieve this through the adaption of dynamic shape display technology and implementation of springs.

To be able to achieve this, the objectives are as follows:

- The determination of the configuration of springs the is most effective in resembling different terrain hardness.
- The feasibility of implementing dynamic shape display technology with the system used to recreate ground hardness.

1.3 Limitations

Due to the nature and settings of this project and the COVID-19 pandemic of 2020, there are limitations to this project. These limitations are as follows:

- Desktop prototype will not be optimised as best it could be due to time and material restrictions.
- Limited motors were able to be obtained due to shipping delays cause by COVID-19.
- The technical knowledge will limit the ability to fully integrate the proposed design into a virtual reality technology and hence this aspect will be placed out of scope. The focus will remain on the feasibility of the proposed subsystem.

1.4 Conclusions

Upon the completion of this project it is anticipated that the following outcomes will be achieved:

- A preliminary design for a system that will allow the feel of different terrain types to be replicated and for the walking surface to replicate the typography of the virtual landscape automatically will be developed.
- The feasibility of combining the surface hardness and dynamic shape display technologies will be explored.
- The feasibility of implementing the investigated technology into a virtual reality treadmill will be investigated.
- To create a basis for further research into exploring dynamically adjusting virtual reality treadmills for the ability to create a truly immersive virtual reality experience.

2 Background Information

To achieve a complete understanding for the motivation behind this project, it is a requirement that there be an understanding of virtual reality technology as well as virtual reality treadmill technologies.

2.1 Virtual Reality

Virtual reality is an innovative technology that allows users to feel like they are in a different environment which is displayed through a headset. This concept was once viewed as only capable in the movies but with the progression of technology, virtual reality is now readily available to everyday consumers. A virtual reality system usually contains a headset, controller/s and usually a computer or system to run the programs on. The headset is designed to deprive the user of their ability to see anything except the images displayed in the headset which is how the system creates an immersive environment. The controllers are used to allow the user to interact with the environment and in some instances the virtual reality system does not require controllers at all and utilises cameras to decern the positioning of the user's hands. An example of a system in use is displayed as Figure 2.1.

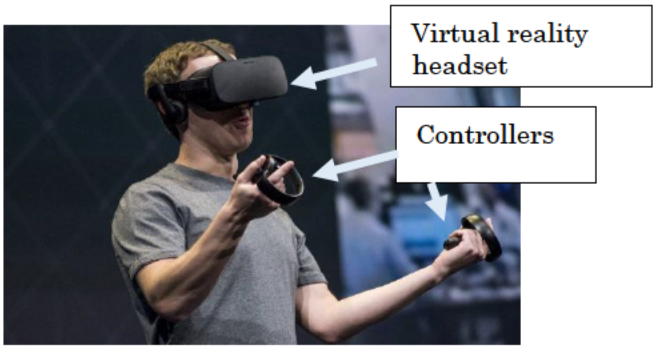


Figure 2.1: Virtual reality headset and controllers (Peckham, 2016).

2.2 Virtual Reality Treadmills

Virtual reality treadmills were developed to help make the experience of using virtual reality more immersive. The concept of virtual reality treadmills is to allow the user to freely move around the virtual space without being limited by the size of a room. This is done by using a walking platform which is defined by the type of virtual reality treadmill. There are two classifications of virtual reality treadmills; omnidirectional treadmills which utilise a moving walking platform and slidemills which utilise a concave, low friction surface. Both types of treadmills are explored below.

2.2.1 Omnidirectional Treadmills

Omnidirectional treadmills are similar to conventional treadmills except that their walking surface is able to move in four directions (forward, backward, right and left) instead of just one (forward). The reason why an omnidirectional treadmill can move in these directions is due to the aim of trying to keep the user in the centre of the walking platform. Although the concept to do this seems simple, the user must be recentred with as little inertia acting on the body as possible. It is essential that the user does not feel the inertia as the user must remain unaware that they are in motion after they have stopped moving in a direction as this can cause a disconnect between the virtual space as well as creating the potential of motion sickness. There are two sub-categories of omnidirectional treadmills: belt-driven and roller-driven designs.

An omnidirectional treadmill that has a belt-driven design has one large "belt" that moves in what would be perceived as the forward and backward directions and a smaller belt wrapped in a way that looks like many small belts that move in the perpendicular direction to the main belt allowing for sideways movement. The ability to move in any direction is achieved by a combination of both the large and small belts moving together to create diagonal movements and in turn if the user only wants to move forward only the large belt needs to operate. As a machine can never predict human nature and in turn never predict when the user will stop, the machine is never able to keep the user exactly centred and hence the need to constantly adjust the users position back to the centre point. Although there is research underway using the users point of centre of gravity, there is a way to go before this system will become truly immersive for virtual reality technology. An example of this type of system is displayed in Figure 2.3.

Figure 2.3: The Infinadeck omnidirectional treadmill with a belt-driven design walking platform (Lodola, 2018).

A roller-driven omnidirectional treadmill utilises rollers as the moving surface. These rollers are made into triangular sections with the roller length decreasing as it gets closer to the centre of the platform. The triangular sections are then positioned in a way that makes a quasi-circle with the apex of the triangles meeting in the centre of the platform. All the rollers are controlled by a single motor as they all must rotate at the same speed otherwise harm may come to the user. Like the belt-driven treadmill, the roller-driven design's goal is to keep the user as close to the centre of the platform as possible which means it also suffers the same pitfalls as the belt-driven treadmill as the user must not feel themselves being recentred. This type of omnidirectional treadmill is shown in Figure 2.2.

Figure 2.2: The Omnideck - a roller-driven design omnidirectional treadmill (Lodola, 2018).

2.2.2 Slidemills

Slidemills are not treadmills in the traditional sense as they do not have a moving walking platform. Instead, slidemills have a low friction, concave surface for the walking platform. Slidemills function as a treadmill by using the user's weight, gravity, and the low-friction surface to bring the users foot back to the centre of the platform every time they take a step. Although the feeling of walking on a slidemill does not feel organic, it is one of the best representations on the market as it does not need to produce any inertia on the body as the user does not move from their original location as they are fixed in a harness. The appeal of the slidemill to companies is the lower cost point due to the lack of moving parts which allows the cost to be reduced. An example of a slidemill that is available on the market is shown in Figure 2.4. For this project, when talking about the feasibility of implementing the developed technology into a virtual reality treadmill, a slidemill is what is to be referenced.

Figure 2.4: Picture of the Omni Virtuix - a slidemill currently available to consumers (Lodola, 2018).

3 Literature Review

Due to there being no previous literature undertaken on this pacific problem, a review of the literature related to dynamic shape display technology and tactile displays will be undertaken to help create the basis for the project.

3.1 Dynamic Shape Displays

Dynamic shape display systems, in their primitive forms are much the same as a Pinscreen which is displayed in Figure 3.1. Pinscreens are a flat plane that has many small pins interested into it and these pins can freely move on one axis (forward and backward). The pins are not automated and can only move if human input is received in the form of a push. Once the pins have been pushed, depending on the number and pattern of pins pushed an image is able to be seen on the reverse side of the plane such like the hand displayed in Figure 3.1. Dynamic shape display's take this concept and have evolved it to so that the pins actuate themselves after an input is received from a computer or user.

Figure 3.1: A Pinscreen displaying the impression of a hand.

Dynamic shape display devices are a new class of input/output devices that can dynamically render physical shapes and geometry through the deformation of their surface topography (Leithinger et al., 2015). They are classed as an input device as they can take input from multiple sources such as computer as well as human input. Leithinger et al. (2015) undertook a project named inFORM that can distinguish when a user is pressing down on the pins as well as if they pull them. This allows the system to respond to different inputs which may be in the form of a button created with the pins that can be pushed by the user or a graph that can be pulled or pushed to increase the magnitude of the graph. Most shape displays are capable of taking input from a user with projects undertaken by Iwata et al. (2001), Wagner et al. (2002), Poupyrev et al. (2007) and Kammermeier et al. (2000) to name a few. The output portion of dynamic shape display technology is due to the pins being able to create shapes. As Leithinger et al. (2015) states, dynamic shape displays are unable to fully recreate three dimensional objects and instead creates a 2.5 dimensional object due to the nature of the pins rising from the base, it is because of their connection point at the base that the system is unable to create overhangs and hence not organic three dimensional shapes as displayed in Figure 3.2.

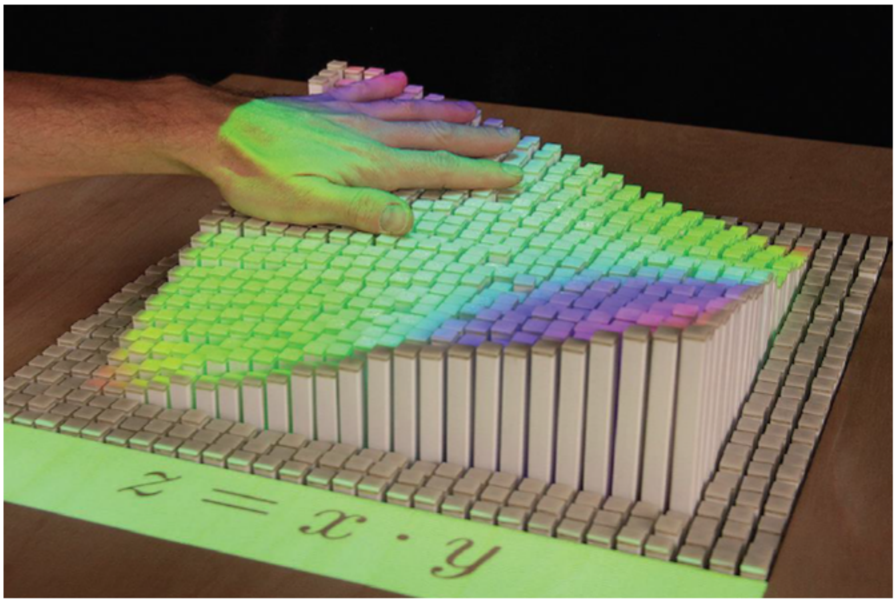
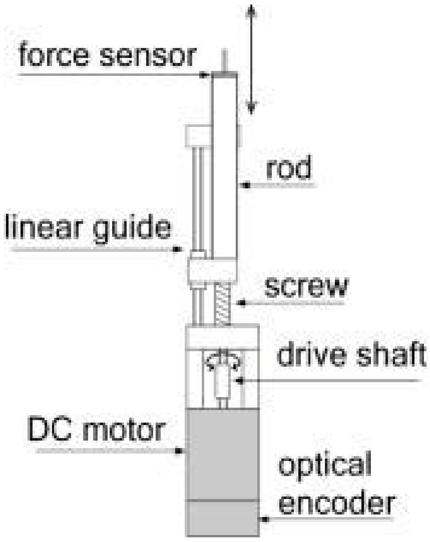
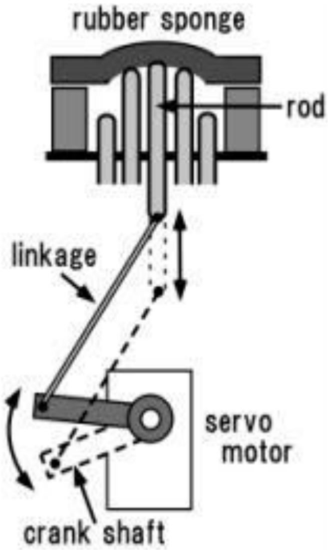


Figure 3.2: Display of inFORM demonstrating the 2.5D possibilities and the inability to create overhangs (Leithinger et al., 2015)

The surface of the dynamic shape display technology can adapt dynamically depending on the input due to the pins being individually actuated. The type of actuation that is used depends on the project and its specific requirements. The requirements dictate the allowable size of the actuation method as well as the power that is required from them. Leithinger et al. (2015) uses linear actuators of undisclosed description to control the pins and is verified in Eu Jin et al. (2014) who undertook a study involving inFORM and two other shape displays of varying sizes to compare the specifications of each. Iwata et al. (2001) developed two dynamic shape display systems, Feelex 1 and Feelex 2, with Feelex 1 utilises a DC motor for each individual pin and a screw mechanism to convert the rotational motion to a linear one. Feelex 2 however uses a servo motor and a crank shaft for the linear motion of the pins. A schematic of each of these actuation methods is displayed in Figure 3.3.



Feelex 1 Actuation



Feelex 2 Actuation

Figure 3.3: Feelex 1 and Feelex 2 actuation methods (Iwata et al., 2001).

Although the actuation methods used within the Feelex projects, each type has their advantages and disadvantages. The screw mechanism and DC motor used for Feelex 1 is fitted with a self-locking mechanism which hallows the pins to be locked into place when the motor is not running however using this form of actuation is at the expense of speed which is an important aspect for the project at hand. Feelex 2 was a small-scale design and hence the use of servo motors and a crank shaft design, although this allowed for fast actuation, the servo motor is underpower and would not be able to take much input. For the purpose of Feelex 2, this was acceptable as it was designed to help teach doctors to identify tumours under the skin with their fingertips and hence not much force would be rendered. Goulthorpe et al (2001), created a large-scale dynamic shape display that was eight meters long and 7 meters tall which required some power to move its 576 pins. The actuation method of choice for this large system was pneumatics due to their accuracy and speed. The difference in actuation seen from Iwata et al. (2001) and Goulthorpe et al (2001), reiterates that there is no correct actuation method to use for dynamic shape displays as it depends on the requirements of the project as well as sizing. Leithinger et al. (2015) reiterates this problem with their 30x30 pin display being much smaller that the footprint needed to house the actuation methods and necessary hardware as shown in Figure 3.4.

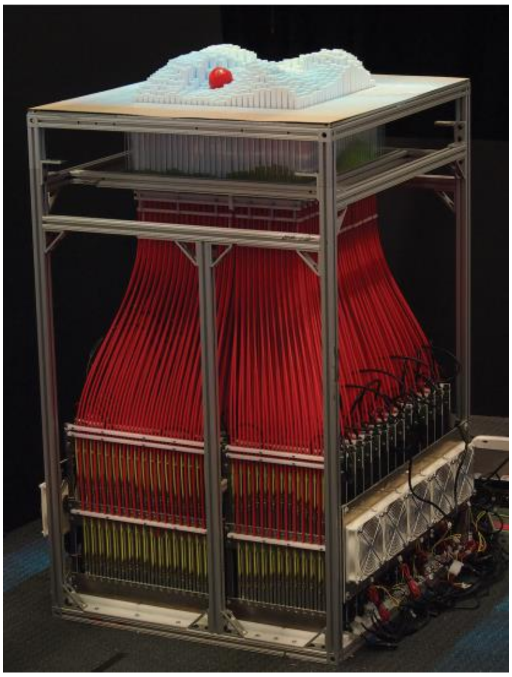


Figure 3.4: InForm displaying the actuation setup for a 900-pin array and the footprint needed for the actuation method and all necessary hardware (Leithinger et al., 2015)

The actuation method can also provide the ability to adjust the feel of the pins and make a surface feel soft or hard. Iwata et al. (2001) was able to do this in the Feelex 1 project with their screw mechanism and DC motor. To be able to achieve this, force sensors, in the form of strain gauges, were placed on the end of each pin. These sensors were used to measure the force that a user was exerting on the pins and adjust the power output of the motor to ensure the pin did not move if a hard surface was desired or retract the pin slowly with the force is a soft surface was desired. This type of setup can be implemented into other shape displays to achieve the same idea and in instances like Feelex 2 where the surface area of the pin is small, instead of using sensors on the pins, the current change within the motor was measured instead to determine the force.

The ability to recognise shapes in the pins is heavily influenced by the resolution of the pins. The resolution is directly related to the sizing and spacing of the pins which is influenced by the motor and/or actuation method used as discussed previously. This concept can be thought of much the same as the resolution of a picture, the higher the resolution the smaller the pixels and higher detail the picture is and the lower the resolution, the larger the pixels and less detail is shown as can be seen in Figure 3.5.

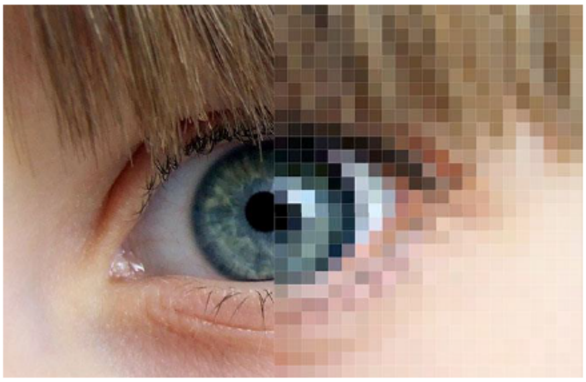


Figure 3.5: High resolution image (left) versus low resolution image (right).

This concept is supported by Goulthorpe et al. (2001) with the Aegis Hyposurface's surface being divided into the smallest possible components which would allow for a fluid motion on the surface whereas Leithinger et al. (2015) opted for larger pins reducing the resolution of the inFORM as a sacrifice for the actuation method chosen. It is also a similar case for Iwata et al. (2001) with Feelex 2 choosing to use servo motors with a crank shaft, as discussed previously, to accommodate the need of fitting all 23 pins in a 50mm by 50mm surface area. It is evident that upon deciding the design of the dynamic surface display technology, a decision must be made which is more important to the purpose of the project, actuation method or resolution of the pin surface. This compromise must be made due to current technology in actuation not being at the point that is needed for compact but strong methods needed for dynamic shape display technologies.

3.2 Tactile Displays

Tactile display devices are devices that interface between humans and computers in the form of reproducing tactile parameters as closely as possible. These tactile parameters are generally for objects and come in the form of shape, surface texture, roughness, and temperature (Chouvardas et al., 2008). There are many tactile displays that have been produced, with many being developed to be attached to the human body to be able to convey the information directly. These devices can be used to help convey information to the blind in various forms as well as to help designers to develop products to cut down design time and the number of prototypes developed.

Mansutti, et al. (2017) created a tactile display to help designers during the shape modelling phase of a project by allowing them to undertake a tactile evaluation of it. Their approach allows the designer to be able to change the shape of the model according to their needs which in turn reduces the number of prototypes that are needed to be produced prior to the final design being reached. This system is displayed in Figure 3.6 and utilises 3 actuators that change the positioning each control point, one actuator that allows the torsion of the strip and a final actuator that is able to control the local curvature of the trajectory.

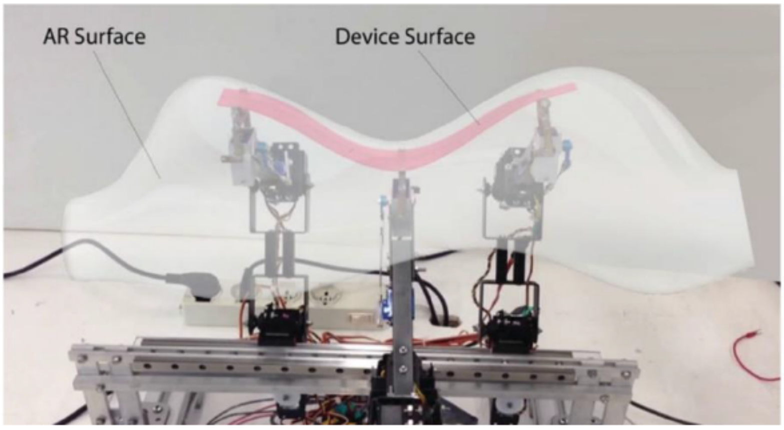


Figure 3.6: Mansutti et al. (2017) tactile display that allows designers to evaluate designs prior to prototyping.

Although this device is not designed to be kept in constant contact with the body, it allows the user to feel the different curvature of the device and when used in the conjunction with virtual reality technology or augmented reality technology the user will feel like they are feeling the actual device they are designing. On the other hand, Gallo et al. (2015) created a small prototype that was designed to fit on the fingertip of the user. This device involved four electro-pneumatic actuations to operate the four pins. These pins can distribute a force of 200mN and displacements over 1mm. Although this is not a large force or displacement in relation to a human fingertip, these quantities should be enough to be felt by the user. Although the purpose of this device was not revealed, the applications are immense.

Jones et al. (2008) and Chouvardas et al. (2008) both developed a device to assist the blind, one to help display Braille and the other to help in navigation. Jones et al. (2008) created a device that was designed to be fixed to the user's abdomen and contained 768 titanium electrodes which can act as the user's eyes to help in navigation. This device can help direct the user with the help of a camera. The light intensity of each pixel from the camera depicts the displacement of each actuator and hence can replicate the image in the camera to the user on their abdomen. Chouvardas et al. (2008) on the other hand created a device that can be used as a graphic display or for Braille. The device is a pin-based design with the pins having only two positions, up or down. By using this device to help display Braille, the difficulties involved with Braille embossed on paper can be overcome although these devices are generally expensive and hence are not very common.

4 Methodology

To be able accurately examine the feasibility of the proposed devices, different tests must be undertaken. These tests are designed to test individual components and a final test of all the systems designed implemented together to test the overall feasibility of the system. For the ease of testing and with limited resources available due to COVID-19, the final feasibility test will only include one pin and its included system.

4.1 Experimental Setup

The first experimental setup is the ground feel replication test and then the topography replication. Each test is outlined below.

4.1.1 Ground Feel Replication

To be able to replicate the feel of different ground types, springs will be utilised. Motors would also be able to be utilised to do the same function however due to the scale of the final design, a more mechanical version was favoured. There are two different configurations of springs that were tested, a single layer and a dual layer system. The concept design of the experimental setup is shown in Figure 4.1. However, this design has be redesigned for ease of comparison and restriction of available materials due to COVID-19.

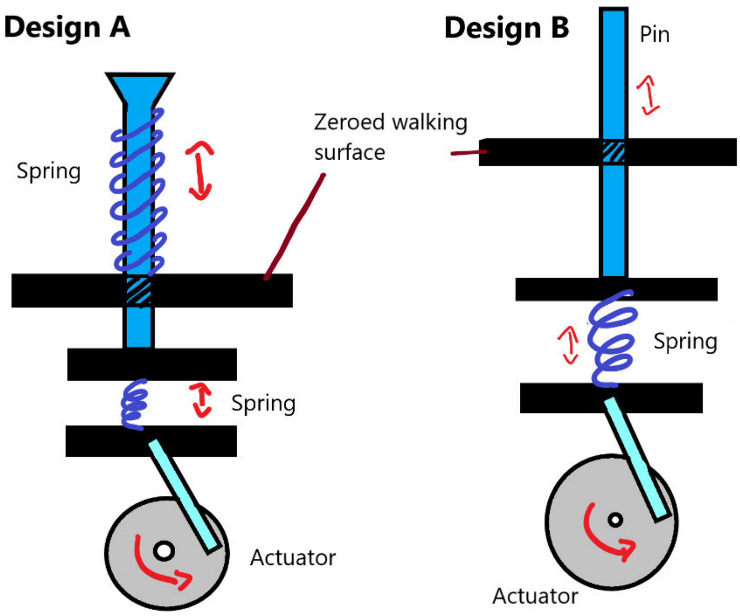


Figure 4.1: Concept design of spring configuration for testing.

Single Layer Spring System

There are two phases of testing the single layer system, with just a single spring implemented and using two springs. The reason to test two springs adjacent to each other is to determine if the stability of the actuation would be increased if the forces were spread over a wider space.

The experimental set up includes a piece of flat balsa wood 185mm x 75mm x 5mm. This platform acts as a base to test the feel of the springs. For the test, twelve springs will be needed with four different gauges being tested. The gauges of the springs being tested, and quantity is displayed in Table 4.1.

Table 4.1: Spring gauges and quantities required for experimentation.

Spring gauge	Quantity
Compression 9/32" x 1/2"	3
Compression 3/8" x 5/8"	3
Compression 3/8" x 3/4"	3
Compression 9/32" x 3/4"	3

The balsa wood base is divided into eight sections as shown in Figure 4.2 (it should be noted that the pin structure has not been attached in this figure). With the bottom four sections containing only a single spring each section with a different gauge and the top four sections each contain two springs of the same gauge but different gauges in each section.

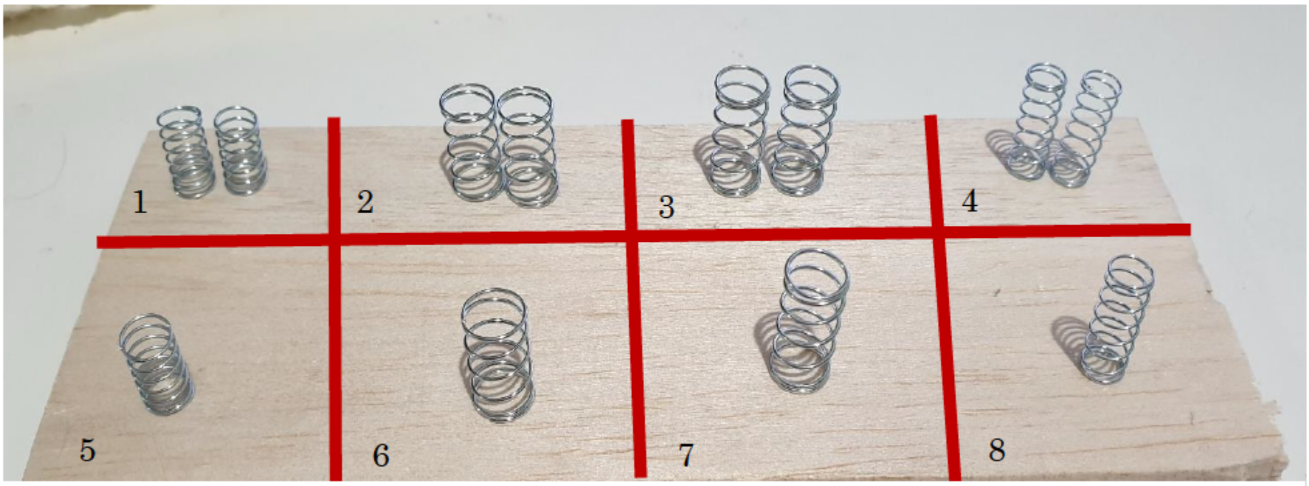


Figure 4.2: Ground feel single layer experimental setup.

The final experimental setup is displayed in Figure 4.3. The springs are attached to the balsa wood (base and pins) via a hot glue gun.

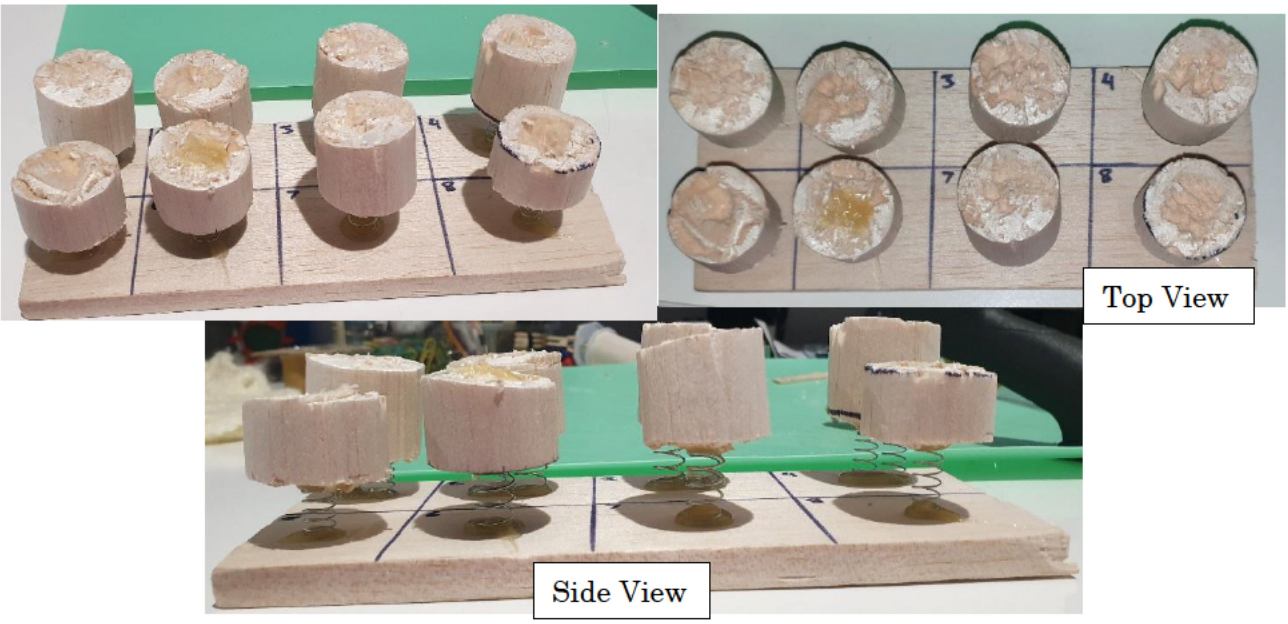


Figure 4.3: Single layer final experimental setup.

Dual Layer Spring System

Due to the size of the pins being used for the experiment, instead of the spring being around the pin as displayed in the concept design shown in Figure 4.1, two springs were instead implemented on either side of the pin as shown in Figure 4.4.

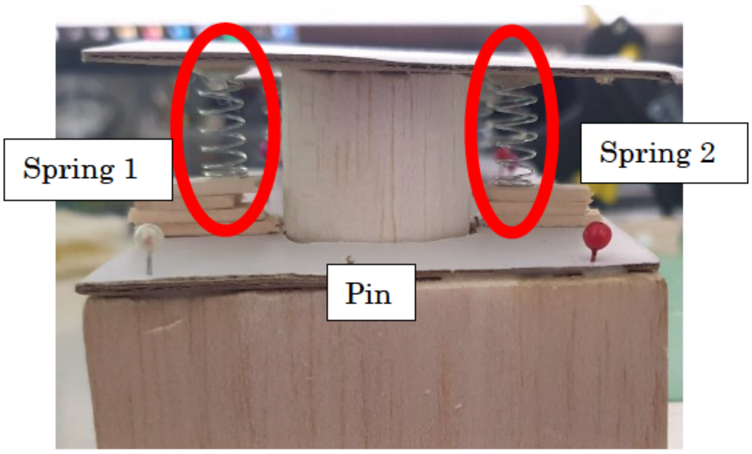


Figure 4.4: Display of the spring design implemented for dual layer.

The gauge, quantity and location of the springs used in this setup is included in Table 4.2.

Table 4.2: Dual layer spring gauge, configuration, and location.

Spring Gauge	Quantity	Location
Compression 9/32" x 1/2"	3	2 above; 1 below
Compression 3/8" x 5/8"	3	2 above; 1 below
Compression 3/8" x 3/4"	3	2 above; 1 below
Compression 9/32" x 3/4"	3	2 above; 1 below

The final experimental setup for the dual layer experiment is displayed in Figure 4.5. Note that there is stacked paddle pop sticks to bring the surface up to the bottom of the spring on the second layer, however in the final design this would not be the case and it would more replicate that off the concept design in Figure 4.1.

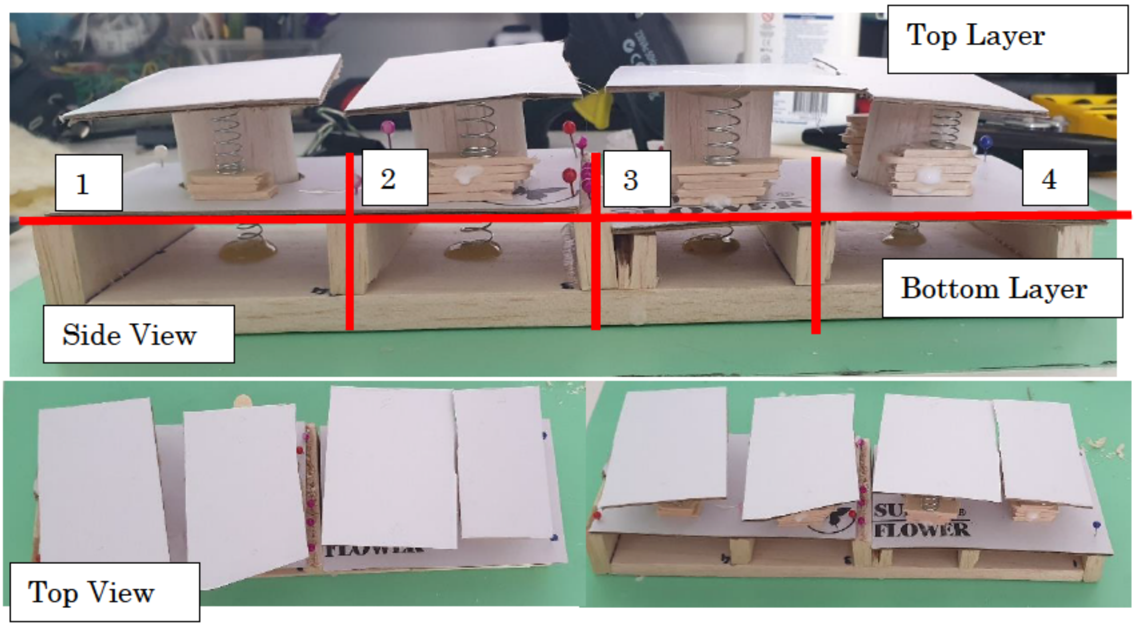


Figure 4.5: Dual Layer spring configuration and location.

4.1.2 Topography Replication

To be able to implement dynamic shape technology, the system used to replicate the feel of different ground types must be encased and then the whole subsystem can be actuated. This allows the surface to be able to change freely while keeping the feel of the surface as intended. For this experiment only a double spring setup for the ground feel type will be used to evaluate the topography replication feasibility. The internal workings of the new pin system as well as the final system (without actuation attached) is displayed in Figure 4.6.

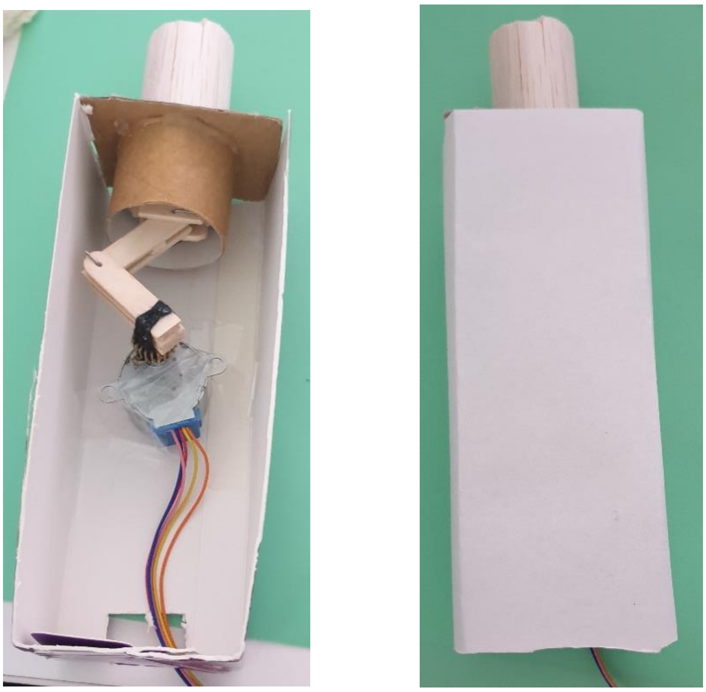


Figure 4.6: Ground feel replication encased for the topography replication system construction (left). Final version without actuation (left).

The actuation for the topography replication system will be a rack and pinion system attached to the outer right side of the casing. The motor will be a servo motor, the same used for the ground feel actuation.

4.2 Data Acquisition

To be able to evaluate the experiments described in Section 4.1, a marking scheme must be constructed.

4.2.1 Ground Feel Test

To undertake the test the pin is set to one of three positions: full up, midway, or full down. The pin positioning is described as follows:

- **Full up**: the spring fully uncompressed i.e. in the dormant position.
- **Mid**: the spring is halfway between fully decompressed and fully compressed i.e. the spring is compressed to half its uncompressed size.
- **Full down**: the spring is fully compressed i.e. the spring cannot compress any further and is in its smallest state.

The marking scheme used for the ground feel test is displayed in Table 4.3 with the test undertaken 3 times.

Table 4.3: Marking scheme for ground feel experiments.

		Test One			Test Two			Test Three		
		Full up	Mid	Full Down	Full up	Mid	Full Down	Full up	Mid	Full Down
Single Layer Section	1									
	2									
	3									
	4									
	5									
	6									
	7									
	8									
Dual Layer Section	1									
	2									
	3									
	4									

The marking scheme will be marked on a scale of one to five, with the meaning of each value being explained in Table 4.4.

Table 4.4: Marking scale for ground feel experiments.

Scale	Meaning
1	The feeling of the pin surface is hard. It feels like concrete, tiles, bitumen, etc.
2	Can neither fit exactly into scales 1 or 3 but is somewhere in between.
3	The feeling of the pin surface is semi-hard. It feels like rubber under surfacing (usually used under playgrounds), standard carpet, etc.
4	Can neither fit exactly into scales 3 or 5 but is somewhere in between.
5	The feeling of the pin surface is soft. It feels like plush carpet, grass, dry sand, etc.

4.2.2 Topography Test

To undertake the topography test, the motor is set to 3 predetermined speeds: slow, medium, and fast with the specific speed recorded at time of recording. The stroke length is defined as the distance that the pin system moved over the period of two seconds and will be recorded for each test. A marking scheme was created to determine how well the system can perform under different speeds and under force and no force loads. The marking scheme for the performance of the system is categorised as good, okay and poor and is described as follows:

- **Good**: The system performs well with no damage to the system. Movement is smooth with no jittering.
- **Okay**: The system performs adequately. There is no or little damage to the system. Movement is relatively smooth with little to no jittering.
- **Bad**: The system performs poorly. There is damage to the system. Movement is not smooth with excessive jittering or unable to move at all.

The marking scheme for the topography test is displayed in Table 4.5. Observations made throughout the experiment will be recorded as well and detailed in Section 5.2.2.

Table 4.5: Marking Scheme for topography experiment

	Test One			Test Two		Test Three	
	Speed	**Stroke Length**	**Performance**	**Stroke Length**	**Performance**	**Stroke Length**	**Performance**
No Force							
Force							

5 Results and Discussion

Within this section, the results obtained for the ground feel replication and topography replication experiments will be displayed and the results will be analysed and discussed. The analysis will include any observations noted during the experimental phase. An analysis of a potential final design will be undertaken and a discussion on the viability of combining the technologies will be undertaken. Finally, an analysis of how the technologies will be implemented into virtual reality treadmills will be undertaken.

5.1 Ground Feel Replication

5.1.1 Results

The ground feel replication experiment was undertaken three times to ensure the results are can be averaged. The results obtained for each test are displayed in Table 5.1.

Table 5.1: Results recorded for the ground feel replication test.

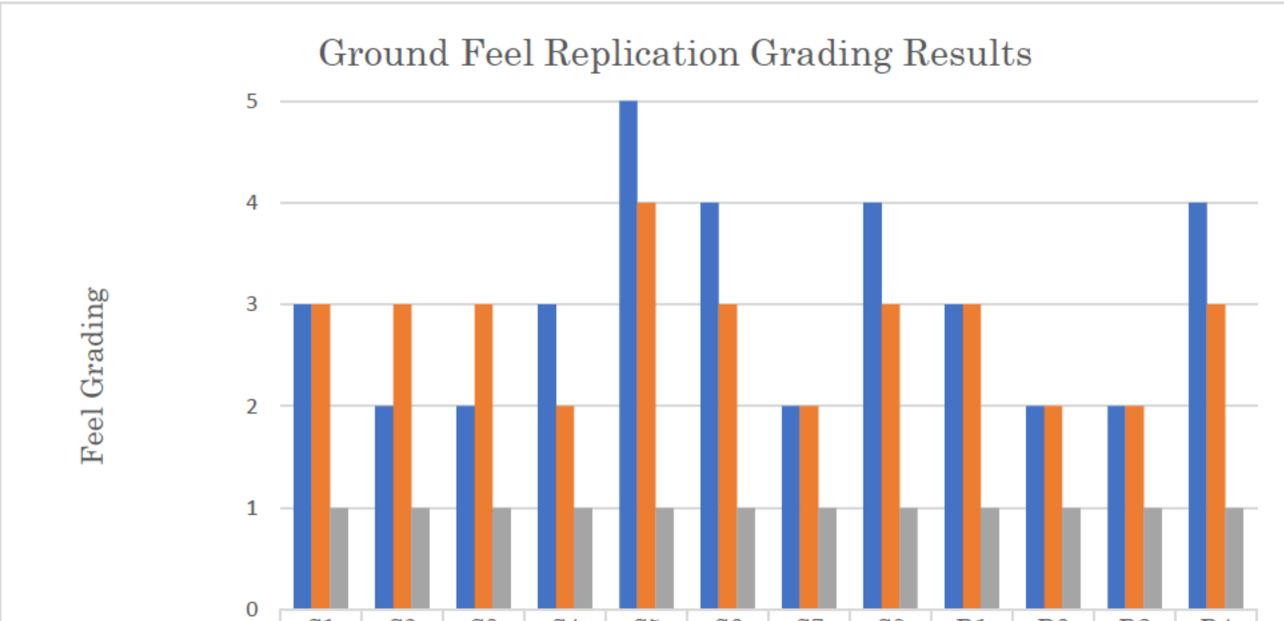
		Test One			Test Two			Test Three		
		Full up	**Mid**	**Full Down**	**Full up**	**Mid**	**Full Down**	**Full up**	**Mid**	**Full Down**
Single Layer Section	**1**	4	4	1	3	3	1	3	3	1
	2	2	3	1	2	3	1	3	2	1
	3	2	4	1	2	2	1	2	2	1
	4	3	2	1	2	2	1	3	3	1
	5	5	4	1	4	4	1	5	4	1
	6	4	3	1	3	3	1	4	3	1
	7	2	2	1	2	2	1	2	2	1
	8	3	2	1	4	4	1	4	4	1
Dual Layer Section	**1**	3	3	1	3	3	1	3	2	1
	2	2	2	1	2	2	1	2	2	1
	3	2	3	1	2	2	1	2	2	1
	4	4	3	1	4	3	1	4	3	1

The results shown above are averaged over the three tests to determine the averaged grading for each spring configuration and is rounded to the nearest whole number. Ideally the grading will be 5 for full up, 3 for mid and 1 for full down, the gradings that meet these points are highlighted green. Results that were recorded more than 2 grades away from the ideal grade are highlighted in red. The averaged grading is displayed in Table 5.2.

Table 5.2: Averaged grading of different spring configurations with ideal and unideal gradings highlighted.

		Full up	Mid	Full Down
Single Layer Section	**1**	3	3	1
	2	2	3	1
	3	2	3	1
	4	3	2	1
	5	5	4	1
	6	4	3	1
	7	2	2	1
	8	4	3	1
Dual Layer Section	**1**	3	3	1
	2	2	2	1
	3	2	2	1
	4	4	3	1

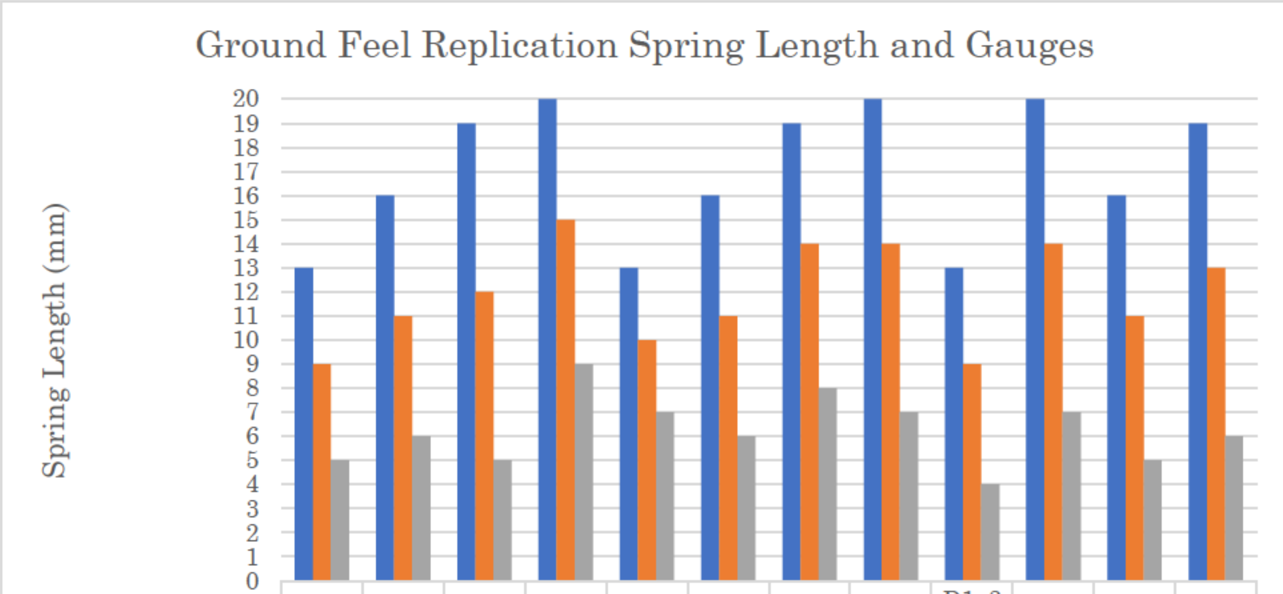
These results can be compared via a graph which is displayed in Figure 5.1. Ideally on the graph there will be a gradual decrease in grading, but it can be seen that some of the configurations do no offer great variation while others offer the variation but lack the desired points. The prefix S stands for single layer and the prefix D stands for double layer.



	S1	S2	S3	S4	S5	S6	S7	S8	D1	D2	D3	D4
Uncompressed	3	2	2	3	5	4	2	4	3	2	2	4
Half Compressed	3	3	3	2	4	3	2	3	3	2	2	3
Fully Compressed	1	1	1	1	1	1	1	1	1	1	1	1

Figure 5.1: Ground feel replication results graph comparison.

For comparison purposes, the lengths of the springs for each of the categories, compressed, half compressed and fully compressed, is displayed in Figure 5.2 with the quantity and gauge of the corresponding springs. This will allow for conclusions to be drawn in the next section regarding the influence of the gauge and size of the springs on the ground feel identified.



	S1: 2 - 9/32" x 1/2"	S2: 2 - 3/8" x 5/8"	S3: 2 - 3/8" x 3/4"	S4: 2 - 9/32" x 3/4"	S5: 1 - 9/32" x 1/2"	S6: 1 - 3/8" x 5/8"	S7: 1 - 3/8" x 3/4"	S8: 1 - 9/32" x 3/4"	D1: 3 - 9/32"x 1/2"	D2: 3 - 3/8" x 5/8"	D3: 3 - 3/8" x 3/4"	D4: 3 - 9/32" x 3/4"
Uncompressed	13	16	19	20	13	16	19	20	13	20	16	19
Half Compressed	9	11	12	15	10	11	14	14	9	14	11	13
Fully Compressed	5	6	5	9	7	6	8	7	4	7	5	6

Figure 5.2: Ground feel replication graph of spring lengths at different compression points and the corresponding quantity and gauges.

5.1.2 Discussion

As stated previously the ideal grading over the test would have been, uncompressed = 5, half compressed = 3, and fully compressed = 1. This theoretically would allow various ground types to be replicated through the compression of the spring/s. Another aspect that is important to the success of this technology is the stability of the pin when it is compressed as the pin must stay in position under a range of different forces which may not necessarily be perpendicular to the pin's walking surface. However, for the purpose of this project, only forces that are perpendicular to the pin's walking surface have been considered and other force directions are out of scope but will need to be considered in further work. It was observed through the experimental phase that the single spring design were the most unstable of all spring configurations. This was observed due to if the force were applied slightly off centre of the pin or if the spring itself had been attached off centre of the pin, the spring would easily buckle. This could potentially be overcome by implementing a guide system however, the guide could only be implemented under the zeroed walking surface as to not obstruct the ability of the pin to become flush with the zeroed walking surface. This is also true for the shorter, wider springs being more stable. This could be due to the shorter springs also being of a higher gauge, so they were more resistant to buckling motion and had less length to buckle over.

When all the configurations, regardless of spring size or gauge, were fully compressed, they were all gauged as 1, with 1 being gauged as the hardest feeling surface such as concrete. This is expected as the spring is fully compressed and hence would not be able to provide any give which is what gives the replication of softer ground feels. It should be noted that the highest grade spring being S3, S7 and D3 gauged at 3/8” x 3/4" was difficult to fully compress with it being almost impossible to fully compress it when there were multiple spring in S3 and D3 designs. This would mean that a high-power motor or actuation device would need to be used to be able to force the spring to be fully compressed. This would not be ideal as higher-powered devices usually require more power and are generally bulkier than their lower powered counterparts. This point is a crucial point that will be discussed in Section 5.4.

From Figure 5.2 and Figure 5.1 it can be seen that there is a direct correlation with the gauge of springs and the harder the replicated ground would feel. This is also true for the increased number of springs. This was intuitive due to the higher gauge spring resulting in a stiffer spring and hence the harder the ground feel would be replicated. Although a higher gauge refers to the thickness of the wire used for the spring and doesn’t necessarily relate directly to the stiffness of the spring, in more cases it is the case. In configurations where a stiffer/higher gauge spring is used in a parallel setup as for the dual spring configurations and the dual layer configurations (top layer), the stiffness of the springs follows the stiffness equations such that:

$$K_{eq\,parallel} = k_1 + k_2 \tag{1}$$

$$Where\ k_x = stffness\ of\ corresponding\ spring$$

$$\frac{1}{K_{eq\,series}} = \frac{1}{k_1} + \frac{1}{k_2} \tag{2}$$

As it can be seen from equations (1) and (2), springs stiffness in parallel setups will always contribute each spring’s full stiffness to the overall stiffness unlike when series configuration.

From Figure 5.1 the hardest/stiffest configurations are S7, D2 and D3 which correspond to:

- S7 - one 3/8” x 5/8” spring
- D2 – three 3/8” x 5/8” springs
- D3 – three 3/8” to 5/8” springs

This implies that have the dual layer of springs increases the felt stiffness to the point of being too hard and would be unable to replicate softer surfaces such as sand or plush carpet. One single layer spring, S7, is one of the stiffest springs as it is the highest gauge spring with a wire size of 3/8" which attributes to it's stiffness. It is noted that although the dual layer of springs is generally stiffer than the single layer ones, but the dual layer offers more stability than in the other configurations. The dual-layer configuration varies from the original concept design as the spring was designed to be positioned around the pin instead of smaller springs implemented either side of the spring but it is assumed that the stability would still be increased from this configuration compared to a single layered design.

There are some discrepancies within the results displayed in Figure 5.1 as for S2 and S3 it can be seen that the feel of the ground is graded as a three when it is half compressed compared to being graded as a two when fully uncompressed. This indicates that it these configurations feel softer when half compressed compared to when fully uncompressed which is a discrepancy. The source of the discrepancy can be accounted for as the methodology for the testing required a person to make judgment calls on the surface hardness. With the test only being undertaken three times, and being done by a single person, an adequate variety of data was not obtained and hence there is a lot of bias towards the results. The bias is created by the person undertaking the tests being the person who fully understands the outcomes and knows the wanted outcomes and hence this could skew the results. Ideally the experiment would have been done a number of times by multiple people to ensure a good range of data was obtained however due to this methodology being taken up late in the project there was inadequate time to undertake and ethical review as required by the University of Southern Queensland.

5.2 Topography Replication

5.2.1 Results

Similar to the ground replication test the topography replication tests were conducted three times to ensure consistency. The results obtained from the topography replication test are displayed in Table 5.3.

Table 5.3: Topography replication test results for all three tests.

	Speed (RPM)	Test One Stroke Length (mm)	Test One Performance	Test Two Stroke Length (mm)	Test Two Performance	Test Three Stroke Length (mm)	Test Three Performance
No Force	9	14	Good	13	Good	14	Good
	15	27	Good	27	Good	27	Good
	20	35	Good	32	Good	32	Good
Force	9	10	Okay	11	Okay	11	Okay
	15	24	Okay	25	Okay	22	Poor
	20	30	Poor	34	Poor	29	Poor

These results are averaged over the three tests and are displayed in Table 5.4. For the performance criteria it was averaged by allocating the most prominent criteria that was obtained for each test run. This means if for the three test runs, two runs obtained an okay grade and a poor grade the performance grade that would be averaged would be an okay grade. In the case that the three tests return a different grading each time (good, okay and bad), a grade of okay will be assigned.

Table 5.4: Averaged topography replication results.

	Speed (RPM)	Stroke Length (mm)	Performance
No Force	9	13.7	Good
	15	27.0	Good
	20	33.0	Good
Force	9	10.7	Okay
	15	23.7	Okay
	20	31.0	Poor

The averaged results are displayed as a graph in Figure 5.3: Topography replication stroke lengths graph. for ease of comparison. The performance grading for each of the tests are not displayed as there is no need to display this information further as it is readily available in Table 5.4: Averaged topography replication results..

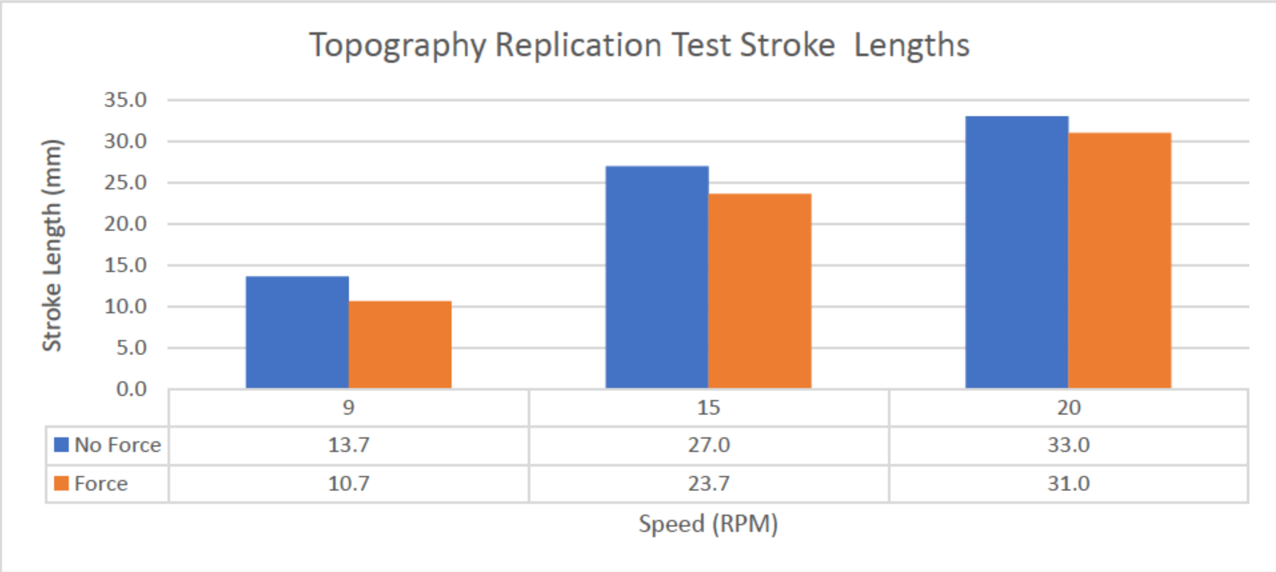


Figure 5.3: Topography replication stroke lengths graph.

5.2.2 Discussion

The ideal outcome from the testing would be for the system to receive a grading of good for the fastest RPM under load. This is because the system needs to be able to adapt quickly and smoothing while a user is walking or running on the pin surfaces. This action will create constant forces on pins in the locale of the user's feet positions however it is not envisioned that the surface will alter directly under the user's feet. It can be seen from Table 5.4 that the fastest speed of 20 RPM resulted in a good outcome when no load was applied but a poor outcome when force was applied to the pin. This indicates that if the pins were able to move without any potential loading on them then the design setup would be adequate to achieve the goals however it is anticipated that during operation the system will inevitably have to move while a force has been applied to the pins and hence with a grading of poor under these circumstance the system would not be able to function as intended.

During the force tests where a force was applied to the top of the pin system while it was in motion, it was noted that the motors used was stalling and slipping slightly if the force applied was too grate but was able to overcome the force when it was alleviated slightly. This shows in Figure 5.3 as the stroke lengths recorded for all the force tests were shorter than that of the tests undertaken without a force applied. Although this is a significant observation in the testing, this phenomenon can be overcome be changing the motor with a higher power motor that would be able to overcome these forces. It should be taken into account though that the size of the motor must be considered in the final design of the system as there are space restrictions and power supply restrictions which will be discussed in Section 5.3.

To be able to accurately replicate different landscapes and environments that could be displayed in the virtual reality environment, it is necessary for topography system to have large stroke lengths. This is due to if there was a rock, the pin system would need to be able to increase in height more than just a few centimetres and would instead require something in the range of 20 centimetres to be able to accurately replicate it. This will require the pins to be able to move sufficiently fast to be able to almost cover the full stroke length instantaneously without causing damage to the system. Figure 5.3 shows that with a speed of 20 RPM the system was able to cover approximately 30mm in the span of one second. Considering that this was tested on a smaller scale system than what would be constructed for a full-scale device, the stroke length would have to be increased ten times to achieve the desired stroke length. Ideally a slightly faster speed would be used to produce a bigger stroke length which given that the system was already graded poorly when a load was applied to the fastest speed, is not a viable option with the current setup and would only be able to be considered if the motor were to be replaced with a more powerful one.

The system was able to perform well under no forces as can be seen in Table 5.4 with all tests being graded as good. This can be accounted for due to the overall pin system being light and hence the weight being applied on the motor to move the system up was negligible. This however is not a realistic expectation of the final design as the pin system would be made of studier materials due to the everyday forces that it will have to overcome. These forces include btu are not limited to a person running, jumping, stomping, etc. on the surfaces of the pin systems.

5.3 Final Design

The final design of the system must have a fast reaction time to be able to adapt to different landscapes quickly. It is also required that the system be stable and sturdy to be able to withstand the user running or walking on the surface. Using the results obtained from Sections 5.1 and 5.2, the best design for the scaled prototype will be suggested as well as details that have to be considered for a full size design.

The most important part of the final design is the ground feel replication system. It was determined that the main influencing factor within this system is the gauge of the spring. The lowest gauge spring is also the smallest spring and the easiest to compress. This mean that there is not much resistance when the spring is compressed and hence it is unable to produce different ground feels. This means that this type of spring is not ideal for this application and hence is not recommended for the final design.

With the dual layer designs being the most stable which is ideal for the system, they are however also the stiffest of the configurations as discussed previously. Although the stability of the system is desirable, the final design for a dual layer system would include only two springs with the spring above the zeroed walking surface being wrapped around the spring (if the spring size allowed). This should still allow for the stability of the design, however, the stiffness of the design will be reduced and hence may make the dual layer design viable for the final design. Without further testing on the spring system and their configurations, particularly using a combination of different springs or including the spring being around the pin, the final design cannot be recommended without further work.

If disregarding looking into further work, and only looking at the configurations tested throughout this study it is recommended that the spring configuration used for the final design would be the S6 spring which includes a single spring of 3/8" x 5/8" gauge and length. Although using a single spring configuration forfeits stability, the ability of spring to be able to replicate multiple ground types as evident in Figure 5.1 as each compression step reaches the target except for the fully uncompressed step which was graded a 4 instead of a 5. This difference is acceptable as when walking on a soft surface, the difference between grades 4 and 5 may not be noticeable through the users feet whereas it can be more noticeable when the user presses on the pin with their hand. To be overcome the lack of stability, care will have to be taken during construction to ensure that the spring is perfectly centred and a guide track should be implemented to help keep the pin straight however, this guide needs to be under the zeroed walking surface as to not interfere with the actual walking surface.

The design for the topography system needs to be able to adapt quickly to the changing virtual reality landscape. The system is also required to be able withstand forces that may be caused by the user running, jumping, walking, or stomping on the walking surface without failing. Through testing it was found that the motor used was not sufficient to be able to withstand forces on the system. It is due to this the no recommended speed or motor will be advised as further testing needs to be done with alternative motor choices. It was found through testing that the ground feel replication system and the topography replication systems were compatible in functioning together as there was no jittering through the tests. The two systems essentially functioned separately without interfering with each other however, this could potentially change depending on the final design configuration and motor choices although it is unlikely.

5.4 Virtual Reality Treadmill Integration

The final step in the project is to look at potential integration of the developed systems with that of virtual reality treadmills and to assess the viability of the two technologies coming together.

Seeing as there are two types of virtual reality treadmills, omnidirectional and slidemill, the focus will be on slidemills as they do not involve a moving walking surface which would create a number of problems which would be hard to overcome. Slidemills do not have a moving surface and use gravity to reposition the user's foot to the centre. To be able to integrate the slidemill system with the topography and ground feel replication systems, further work will have to be done to determine how this concept will be able to function with the new systems integrated to it.

When integrating the designed system with slidemill technology it is important that the size of the pins and actuation used should be debated. The pin size should ideally be sufficiently small to allow a high-resolution replication of the topography but also not too small that the actuation method would not be able to withstand the forces. The pin size that should allow an accurate replication of the topography would be a size between three centimetres and one centimetres, however, this is subjective to the size of the motor and the actuation method used for the ground replication system. This is due to the ground replication system having to be encased in the topography system. The actuation system and motor of the topography replication would also determine the spacing of the pins as the motor must be positioned next to the encased system to allow it to actuate in the vertical direction. Some space can be saved by lining up the motors in such a way that adjacent pin structures' motors could be positioned on top of each other however, this would lead to uneven spacing between the pin structure in certain places.

The final aspect of integrating the different systems together is the power supply and computational power needed to run the systems as multiple pin systems would be in motion at a given time and sometimes all of the systems will be required to be in motion at the same time. The sheer number of pins that could be involved in the final project could require a mass of computational power which can require multiple processes. Each motor involved in the systems also must be powered by an external source which has to be taken into account to ensure that enough power can be obtained from a conventional wall socket. With a large amount of computational power and actual power involved in a system it is essential that the system be sufficiently cooled as well. All of this will need to be considered in further work and development of the project.

6 Conclusions

The purpose of this project was to investigate different spring configurations that would allow the replication of different ground types, to investigate the feasibility of integrating dynamic shape technology with the ground feel replication technology and lastly, to investigate the feasibility of integrating both of these technologies with virtual reality technology. These points were investigated through the conduction of two different tests, one testing different spring configurations and the ability to replicate different ground feels and another test that would test the systems joined together for the purpose of testing the viability under force and no force loads.

6.1 Recommendations

The recommendations taken from the test results are as follows:

- Spring configurations with only one spring were unstable if the spring was not centred properly or if the force was not directly perpendicular to the pin surface.
- The dual layer configuration although offered more stability were generally a stiffer and were unable to replicate softer surfaces.
- To be able to achieve all the required ground feel types, hard, medium and soft, it was recommended that for the prototype a spring of 3/8" x 5/8" gauge and length should be used as it offers the best variance in the grading criteria.
- During the testing phase oof the ground feel replication, it is recommended that a survey of multiple people be undertaken to ensure a wide variety of results and to eliminate bias.
- The ground replication system and the topography replication system are viable together and do not influence the individual systems involved.
- The motor used for the ground replication system will need to be revised as it could not withstand forces being put on the system.

6.2 Further Work

To see this project to completion, it is recommended that the following further work be undertaken:

- Investigations into different spring configurations including using different springs in a single configuration.
- Investigation into viability of increasing the sizing of the springs to accommodate a full-scale model.
- Investigation into alternatives to springs for ground feel replication such as intelligent actuation or potentially a type of air system that inflates and deflates depending on the ground feel wanted.
- Investigation into sizing of motors that are sufficiently strong to withstand the needed forces but small enough to not influence the spring sizing.
- Full integration into virtual reality treadmills.
- Integrating the technologies with virtual reality programs.

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Appendices

Appendix A – Project Specification

For: Cassandra Sandl

Title: Adaption of Dynamic Shape Display Technology for use with Virtual Reality Treadmills

Major: Mechanical Engineering

Supervisor: Tobias Low

Enrolment: ENG4111 - ONL Semester 1, 2020 / ENG4112 - ONL Semester 2, 2020

Project Aim: To adapt dynamic shape display technology for use with virtual reality treadmills.

Programme: Version 3, 26th August 2020

1. Research information about current dynamic shape display configurations particularly regarding actuation design.
2. Determine a preliminary design for the system that can mimic ground feel/type as well as have an adapting surface.
3. Testing of different configurations of springs (1 spring, 2 spring, under zeroed walking surface, above walking zero surface, etc.)
    a. Determine best configuration by qualitative analysis through the creation of a marking criteria.
4. Use of a test scheme to analyse the best configuration.
5. Determine the viability of such technology
6. Determine the viability of incorporating dynamic shape display technology with the ground feel mimic technology. (Can it work).