

Haptic feedback using skin stretch within a teleoperation system

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BSc Report

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Abstract

Endoscopic operations are common in the biomedical world. In operations as removing a tumour or gathering information about the cause of certain symptoms is it a useful tool. The endoscope, which is inside the body, is controlled by an external controller. This is called a teleoperation system. The doctor operating the system needs feedback about what surrounds the endoscope in order to prevent the endoscope from hitting or even penetrating bodily tissue. This risk can be decreased when the feedback is improved. Force feedback, vibration or visual feedback are types of feedback which are already researched and used. The aim of this research is the try to implement a new type of haptic feedback namely skin stretch. Some research already has been done on using skin stretch but it is still in an early stage of development. In this research more precision towards directional skin stretch feedback is added to bring it to a new level. This is desired because a doctor should be able to move the endoscope precisely. A small system is designed which has a sticky end effector attached to the skin. The structure surrounding the end effector has 4 servo motors attached to it which are able to pull the end effector (and thus the skin) in any direction. The skin stretch feedback is tested with a computer, the mouse should be moved along a certain path which is invisible for the user. The user has to trust the feedback in order to follow the right path and finally get to the correct end point. The results show that people have a hard time identifying in which direction the feedback moves. It is also shown that people are able to improve themselves with more training. Finally are the results compared with visual feedback and a combination of both. This comparison points out that the combination of both types of feedback works the best. Therefore can it be concluded that it is a helpful tool towards the operating doctor.

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1 Introduction

Endoscopic surgery is used for many applications within the bio-medical world, just to name a few; during pregnancy, for tumor removal or to investigate ear symptoms. Bringing in an endoscope is not without any risks, damaging or perforation of body tissue is one of the risks involved whit an endoscope. Weak body tissue such as colon walls or blood vessels can easily been damaged. Since endoscopes give the doctors much useful information about the cause of certain symptoms or help during surgery it is worth taking this risk. Yet can the health care become even better when the change of this risk is decreased or even better fully taken away. This can be done by giving valuable feedback to the doctor controlling the endoscope. Visual feedback is often used since and endoscope has already a camera placed on it. Force feedback is another kind of feedback which is a useful asset to the operator of the system. The last example is vibration feedback, which guides the operator by vibrating on a certain frequency related to the direction and a certain amplitude within the vibration is related to the amplitude needed for the right adjustment of the endoscope. The question arises if there are more useful kinds of feedback which can be used in order to improve the whole system. Since especially haptic feedback is used (force and vibration) would it be interesting to see if a relatively new type of haptic feedback, skin stretch, can be helpful. This research tries to find an answer to the question, is skin stretch a helpful feedback in order to control an endoscope. This is compared with visual feedback and the combination of visual and skin stretch feedback.

The first step is taken with diving into the control of the system and into the haptic feedback, skin stretch. After which the sensitivity of the skin and use of skin stretch until now is examined which is all done in chapter 2. Improvements are proposed which are transformed to requirements in chapter 3. These requirements are used within the design and in the creation of the test setup. The design and test setup are realized and tested on the requirements set in chapter 3, the findings of the testing of the requirements are stated within the realization (chapter 4). Finally is the system tested on a few people in order to see the impact of it in chapter 5, adjustments made are described as well. After this is the system tested on a larger group, the results are given in chapter 6. Finally is the question answered which was stated in the beginning, is skin stretch an helpful feedback in order to improve the operation of a endoscope, compared to visual feedback or is the combination of both even better.

2 Theory

To control the end effector of an endoscope an teleoperation system can be used. The controller is such that it can control the endoscope towards any direction desired. As it is inside the body and is able to move in any direction it should be controlled carefully. Knowledge about the surrounding is very important here. Skin stretch will be used to provide this. In order to communicate this information are the properties of the skin important. When these are known a system can be designed which makes use of these properties.

2.1 Teleoperation system

An teleoperation system is in definition a system where the controller is a certain distance separated from the actuator. The Phantom Omni is a controller which can be used for teleoperations. This is a device which can register movement in 6 DOF and generate vibration or force feedback. The system is shown in figure 2.1. The system it self is not of great importance only the background and primary functions of it [3]. The other end of the teleoperation system is often a endoscope but can in theory be any tool useful for any operation, as long as it can be controlled properly inside the body. This way it is possible for a doctor to operate a patient even while he/she is not even near the patient. An important improvement is that specialized doctors can operate many people around the world without traveling. Which decreases the cost of a operation of a specialized doctor and increases the amount of operations he/she can perform on a day. Therefore improves it the quality of health care.



Figure 2.1: Phantom Omni [3]

2.2 Haptic feedback

As already mentioned is the Phantom Omni able to deliver force and vibration feedback. These both are haptic feedback's which give the user much information about the surroundings of the end effector. Force feedback is intuitive to the user and therefor a feedback which does not require the user to learn to deal with it. The down side of it is that it steers the user in a certain direction. When the system is wrong the user has a hard time bringing the controller to the other side. With vibration feedback this is no problem. The down side of vibration feedback is that it does not automatically include directional feedback. Which means agreements have to be made about how this is communicated to the user. An other type of haptic feedback which is not delivered by the Phantom Omni is skin stretch. In order to extend the ways of communication the feedback to the user the research will focus on implementing this. This will be done in such a way it can be used with the Phantom Omni.

2.3 Skin stretch

Skin stretch is a relative new method of haptic feedback. Some researches done can be found but also these are in a early stage, to see the examples is left to the reader but will also be discussed later, [8] and [6]. As the name implies is the skin stretched into a certain direction to let the user feel the systems output. The system is via skin stretch able to give information about a direction together with a certain amplitude. Directional feedback can be delivered if the feedback system is created such that it can stretch the skin in multiple directions. This way controlling a device which has to move in a certain direction can be rather easy. The feedback can steer the user towards the right direction and correct if the user moves in the wrong direction. With skin stretch amplitude variation is also possible. This can be done separately, when only the speed of something or the force on something applied by the user is of importance for example, but it can also be used in combination with the directional feedback. This way the system can correct the user strongly if he/she is further off track and more carefully when the job has to be done more precise. Important with both implementations is the sensitivity of the skin, which can be a limiting factor.

2.3.1 Skin sensitivity

As mentioned is skin stretch a new method of haptic feedback therefore is research on it lacking. Amplitude and directional skin stretch feedback are researched but both separately. With respect to the amplitude it is known that on the fore arm the skin is able to feel directional skin stretch feedback from only 0,13 mm [6]. This gives a lot of options in the skin stretch feedback. The amplitude with which the skin will be stretched can be really small while the user should still be able to feel it. This means the skin stretch can even be used when the user has to be corrected with a small step. This should be kept in mind when designing the system. Since the threshold is such low the best option during design is to let it out in the beginning and scale the amplitude such that it always surpasses this threshold. Directional precision is the other consideration. The feedback would ideally give the feedback as precise ass possible. There is only a small problem which is that a human can not distinguish one degree of change in the direction of the skin stretched. The smallest angle a human can distinguish is about 15 degrees as was researched by David V. Keyson and Adrianus J.M. Houtsma [8]. This might be a bottleneck since the preciseness of the feedback goes down. When the user is less then 15 degrees of the ideal path this can not been told via skin stretch feedback to the user. Yet is it still not possible to use any angle smaller than 15 degrees. When for example the user is corrected with 10 degrees the user would not notice it and therefore not adjust its movement. When after a few seconds again a correction of 10 degrees is applied the total correction is 20 degrees. The user would be able to feel it when this was applied in one step, but since it is now done in two steps which both are smaller then the threshold the user will not feel the second change as well. Therefore would the user be off by 20 degrees. When only steps of 15 degrees are considered the maximum deviation between the actual direction and the direction applied to the skin is 7,5 degrees. If the deviation is bigger the system would simply use a step of 15 degrees higher or lower, which decreases the deviation lower than or equal to 7,5 degrees.

The two important parameters which have the be kept in mind are the minimum amplitude of skin stretch which can be felt by the human skin which is 0,13 mm (on the fore arm)[6] and the lowest angle deviation which a human can distinguish which is 15 degrees[8]. Even though

these researches seems promising it should be kept in mind that directional skin stretch is often only used in a few directions and without amplitude variation.

2.3.2 Skin stretch until now

As already mentioned is skin stretch in a early phase of development. Skin stretch is not used for many applications while it can give a new dimension to many existing technologies. Often are only a few directions used and when done not combined with amplitude variation. The other way around is also done where only amplitude variation is used and directional is left out. A few examples are given below which give an impression of the variety of applications as well of the possible implication methods. One of the applications is the control of a prosthetic arm. Without skin stretch the user can only move it's arm when looking at it, visual feedback. With the use of skin stretch feedback the user has more feeling about how far the prosthetic arm is turned to the left or right. This is done by a half wheel which is pushed against the skin, when turning the arm the wheel will turn as well pulling the skin to one of the two sides [7], see figure 2.2.



Figure 2.2: (left) Structure with rotatable wheel to deliver skin stretch with amplitude variation, (right) structure connected to upper arm to deliver feedback. [7]

Another example is with directional feedback but without amplitude variation. In this case skin stretch is used to guide the user in a game. Two actuators which can move the end effectors in 4 directions are placed at the top of the joysticks of a game controller. The controller is used in a fishing game. The feedback gives the user the feeling of the waves witch you would normally feel with your fishing rod. When a fish is on the hook the haptic feedback actuators will mimic the jerking sensation of the fish on the hook. The controller has the same shape as a standard game controller expect for the joysticks where the haptic feedback is included [1], see figure 2.3.



Figure 2.3: The designed controler including skin stretch feedback [1]

The design of the first example gives the idea that with a simple velcro strap the actuator can be held in place to attach it to the skin. In the meanwhile it is still strong enough to deliver the counter force needed to hold the system in place. The second shows that even with small end effectors skin stretch can still have a valuable impact. Both can be useful in the designing phase.

2.3.3 Improvements

As mentioned in 2.3.1 is the skin able to distinguish an angle change of about 15 degrees. This means the directional feedback can be improved compared with the second example of section 2.3.2. With a 15 degrees sensitivity the user is able to distinguish 24 different directions instead of only 4. This way the user should be able to move the system more smooth trough a certain path instead of following the path by going up/down or left/right, with a staircase shape. Which means the user is less likely to hit something inside the body when it is used in practice. With the addition of amplitude variation the system would become even better. If the endoscope is surrounded narrowly by weak body tissue the low amplitude can indicate the user has to move carefully. On the other hand can the user move faster when the amplitude is higher, indicating the endoscope has more moving space.

3 Method

In order to improve the system as is described before, 2.3.3, the system needs some requirements. First of all should the system be able the move the end-effector, which has contact with the skin, in 24 different directions. These directions should be spread out equally around the 360 degrees of a circle in order to let each directional change be 15 degrees. The system should also include amplitude variation. This means the system must be able to vary the amount of stretch applied in any direction. Finally must the system work independently such that it can be used on more applications than only the teleoperation system where it is designed for. Since it is desired to use the system for multiple applications it should also be lightweight and compact. A big machine which is not transportable can not always be used in other applications, for example when the person is moving. This means the final weight and compactness should be such that it can be worn on the hand. These in total five requirements are listed below.

- 1. End effector must be able to move in 24 different directions, each separated by 15 degrees.
- 2. End effector must have a controllable distance from the center.
- 3. System must work independently of teleoperation system.
- 4. System should be lightweight.
- 5. System should be compact.

3.1 End effector movement

In order to move the end effector in more than 4 directions a system can be created which pulls the end effector from multiple different sides towards the desired direction. This automatically creates the varying amplitude since it can be pulled more or less towards a certain direction. Each pulling point acquires a actuator. As the requirements mentioned should the system be compact which means as less actuators, and thus pulling points, as possible should be used. Three points seems obvious, with three pulling points the end effector can move freely in a certain space and therefore it fulfills the requirements.

Nevertheless is four pulling points better. Using 4 pulling points requires one more actuator, but as can be seen in figure 3.1 is the space in which the end effector can move better spread out around the center which makes the circle in which it is actually going to move bigger compared to three pulling points. This way the sides of the pulling points (marked by the black box, in fig 3.1) can be placed closer to each other compared to the 3 pulling points structure keeping the circle where the end effector can move the same. When for example 1 cm of movement is desired to the right, the 4 points pulling system can have it's pulling points placed 2 cm from each other, resulting in a box of 2 by 2 cm. For the three pulling points structure the box has to be 4 by 4 cm big. This means the total surface of the structure is 4 times as big compared to the 4 pulling points system. Therefore it is chosen to use the 4 pulling point system. Pulling actuators can be found smaller than the saving of 8 cm² which means even though one actuator more is used, the structure is still compacter with 4 pulling points.

3.1.1 Wire lengths

The end effector can move in the space described before with figure 3.1. The length of the wires from the pulling point towards the end effector can be calculated with the use of Pythagoras. Since the feedback has a desired direction and amplitude these are the two known variables. As in figure 3.2 is shown can the displacement of the end effector with respect to the middle



Figure 3.1: Three pulling points left and 4 right on one end effector and the space they can reach

been calculated with the amplitude and the direction. This displacement is depicted as dx for the displacement in the x direction and dy in the y direction. When the end effector is moved to the right is this defined as positive displacement, the same holds for the up direction for the y displacement. The displacement of dy and dx can be described with the following equations, 3.1 and 3.2. Since ϕ is chosen to be the angle between the desired path and the positive x-axis an angle of 0 degrees is equal to a movement to the right. This has to be kept in mind when designing the test case and also when the setup is used in other cases.

$$dy = A * \sin(\phi) \tag{3.1}$$

$$dx = A * \cos(\phi) \tag{3.2}$$





When the end effector is in the middle, this is the case when no stretch is applied, the distance between the end effector and each pulling point is equal. This distance determines the moving distance of the end effector and the dimensions of the structure, for now is this distance labeled as "D". With the use of figure 3.2 it is possible to determine the separation of the end effector and the pulling point in the x and y direction. This is, for example, for the first wire D - dx in the x direction and dy in the y direction. For all wires are the different distances given in table 3.1.

Wire	x distance	y distance
1	D - dx	dy
2	dx	D - dy
3	D + dx	dy
4	dx	D + dy

Table 3.1: x and y distances of each wire.

With these parameters known can the Pythagorean theorem been used to calculate the length of each wire needed to reach a certain position. The wires are simply the hypotenuse of the right angled triangles marked with the black numbers 1 to 4 in figure 3.2. Using the x and y distances of table 3.1 gives the following equations and thus wire lengths for each of the four wires.

$$wire1 = \sqrt{(D - dx)^2 + dy^2}$$
 (3.3)

$$wire2 = \sqrt{dx^2 + (D - dy)^2}$$
 (3.4)

$$wire3 = \sqrt{(D+dx)^2 + dy^2}$$
 (3.5)

$$wire4 = \sqrt{dx^2 + (D+dy)^2}$$
 (3.6)

When no stretch is applied the wire lengths of all pulling points are equal to D, this is the start point. When a wire length is shorter than D the actuator should pull the wire back with an amount of D - wirelength. When it is longer than D the actuator should release some wire, the amount of wire to be released is equal to wirelength - D in order to make the total wire again equal to wirelength. This means the actuators should always release or pull with the difference between D and the desired wire length. When pulling wire in is counted as the negative of releasing wire, the amount of wire to be released can be given with equation 3.7.

$$release = wirelength - D \tag{3.7}$$

3.2 Structural design

As the requirements stated in the beginning of chapter 3 should the system be lightweight, compact and work independently. These are the most important requirements to keep in mind when designing the structural design of the system. The structure should have an option to mount it to the skin and the end effector should have enough space to move to actually stretch the skin. A consideration has to be made between the strength of the system and the weight, ass

well between the amount of space to move the end effector and the compactness of the system as a whole. The design consists of three important parts; the base in which the end effector can move and the actuators can be placed, actuators to move the end effector and an moving end effector which is attached to the skin. The design of the whole structure is given below, the total design is given in figure 3.3.

3.2.1 Base

It is chosen to 3D print the base, this because it can be done relatively fast and precise. The base shall be made out of objet, the 3D printer present can print most precisely with this material. In order to keep the structure compact it is chosen to have the actuators on top of the moving space of the end effector. This way the actuators do not make the base bigger on the sides but on the top of the structure. Since the height is not a big deal, because the structure is placed on the skin with the height pointing outwards, this is the best option to keep the structure compact. This choice automatically means that the end effector has a sort of roof on top of its moving space. The structure will be placed on the back of the hand. With the average hand size width being 8,4 cm [2]. It is chosen that the structure should be a bit smaller, the surface of the structure will be 6 by 6 cm in order to fit on each hand. The moving space is chosen to be 4 by 4 cm, this is done by testing skin stretch with the thumb. Measuring the amount of skin stretch applied on the backside of the hand which is still comfortable gives 2 cm. The side walls of the structure can still be 1 cm with these dimension which gives enough strength to hold the roof. The corners are rounded in order to fit better on the hand. The roof should hold the actuators and counter act the forces applied on it from the actuators without bending. Since 1 cm is in theory strong enough for the walls it should be strong enough as well for the roof of the base. With the space beneath if 1 cm in order to move the end effector becomes the base 6 by 6 by 2 cm, which is indeed a compact structure. Trough the roof of the base are made two holes to insert the velcro. This way it can be strapped around the hand. The base is shown from beneath with the described dimensions in appendix B and in figure 3.3.

The base has to keep the actuators stable. Since they are placed on the base it is chosen to have a roof on the actuators which is screwed tight to the base to clamp the actuators. This roof has to be strong but it does not really matter how precise it is created, because the only function it has is to hold the actuators stable. This is why it shall be cut out of delrin. Which is a strong material but since it is laser cut it is created less precise than the base. An advantage of cutting it is that it can be produced very fast. The roof has gaps in it to fit the connecting points of the actuators and to give the rotating wheels some space, see appendix B, the dimensions of these gaps are determined in section 3.2.2. Whit two screws (3 mm) it is screwed to the base where two square holes are made (5,5 mm by 5,5 mm) where the bolts can be placed. As can be seen in appendix B. The end effector will be connected to the actuators with wires. Since the end effector is under the base the walls need gaps to let the wires trough. In these gaps a small wheel is placed in order to lower the friction. The gaps are 3.1 mm wide (see appendix B) and the wheels placed in it are 3 mm wide with a radius of 2,5 mm. A small gap is made in the wheel, radius of 1 mm, in order to connect it to the base and still let it rotate. These wheels are cut out of objet since the preciseness of the wheels is not that important and laser cutting can be done quickly.

3.2.2 Actuators

The actuators have to be small but strong enough to pull the skin. Small servo's are chosen to do the job, these are the sg90 servo's from Tower pro. [9]. These have a stall torque of 1,8 kgf*cm which is equal to about 17.65 N * cm. The force applied on the skin in a research of Karlin Young Ju Bark was 2 newton in order to move it 12,7 mm [6]. The force which is applied to the skin by the actuator depends on the dimensions of the wheel connected to it. Since a servo can

have a max rotation of 180 degrees, the wheel should be big enough to move the wire 2 cm's in 90 degree, in order to pull and release enough wire. The circumference of the wheel should therefore be 8 cm. The radius and thus the arm which is used to calculate the amount of force delivered by the actuator can be calculated with 3.8.

$$r = \frac{circumference}{2*\pi} = \frac{8}{2*\pi} = 1,273cm$$
 (3.8)

With the radius being 1,273 cm the force delivered by the actuator to the end effector (assuming the wire has negligible resistance) is equal to $\frac{17.65}{1.273} = 13.86N$. This means the actuator can deliver much more force than in the previously mentioned research, about 9 times as much, and therefore that the actuators should be strong enough to actually pull the skin. In order to prevent the wire from falling of the wheel, are the sides of the wheel made a little bit higher. This does not influence the system since the wire is not on top of it but it prevents the system from failing. A small gapp is made in these small walls to let the wire out to the side. A hole in the wheel makes it possible to fasten the wire with a screw to the wheel as can be seen in figure 3.3 c and d. The connectors of the actuators are 11,8 mm by 2,5 mm, therefore have the holes in the base and head the same dimensions. The holes for the wheels are determined empirical, with some space left in order to prevent friction.

3.2.3 End effector

The end effector should be big enough to hold a sticker which can move the skin without slipping, but the dimensions of it are limited by the space it has within the base. The sticker is made of a special tape which sticks well to the skin, leukoplast [4]. Double sided tape is used to connect the leukoplast to the end effector. When tried it can pull the skin properly without slipping when a square of 1 by 1 cm is used. The end effector will therefore be 1 by 1 cm. Leaving the space it can move towards one of the sides not 2 cm but 1,5 cm. The circle in which the end effector can move with an equal amplitude towards every direction has an amplitude of $\sqrt{8}$ cm, which can be calculated with figure 3.2. The wires are pulled trough the end effector and with a knot they are secured. There are 4 holes made in the end effector to make this possible, as can be seen in figure 3.3a in the middle.

3.3 Circuitry

The servo motors runs when it is powered with a voltage between 4,8 V and 7,2 V, the stall current is about 650 mA [5]. Since 4 simple AA (1,5 V) batteries can provide both this is the chosen option. The control of the servo is done with an arduino uno. These have a build in library for servo motors which makes it easy to use and can be used in many cases independently of the teleoperation system which was one of the requirements.. The library gives the correct PWM signal out when a certain angle between 0 and 180 degrees is set. The arduino is connected to a laptop which poweres it but also provides the connection to the test setup which will run on the computer. The circuitry is given in figure 3.4. The arduino can be used to map the desired angle and amplitude to the correct wire lengths. When the correct wire lengths are calculated it can map those to the correct angle of the servo and tel the servo's to adjust themselves to this angle.

3.4 Test setup

The test setup has to mimic the situation of a doctor guiding a endoscope inside the body. Therefore it is chosen to use the mouse as the teleoperation controller. The user can use the mouse to follow a certain path which is not displayed on the screen. The user has to trust the visual and/or haptic feedback in order to find and follow the correct path. Visual feedback has



Figure 3.3: From left to right, top to bottom, the whole structure seen from different sides. a: Bottom view, b: Side view, c: Top view, d: view under a angle

to be tested separately from haptic feedback but they have to be tested combined as well. This will give more insight about how good the feedback works, which works better and which the user desires the most. The software has to give the right angle and amplitude to the arduino in order to let the haptic feedback move to the correct position. In the mean time should the program store the path of the user in order to compare it with the desired path. These requirements are listed below, when the software is written these have to be kept in mind.



Figure 3.4: Arduino controlling the servo's powered by 4 AA (1,5V) batteries.

- 1. Software should create a path which the user has to follow.
- 2. The test setup should test visual feedback, haptic feedback and the combination of both.
- 3. Software should communicate the right angle and amplitude to the arduino.
- 4. The path of the user has to be stored.

3.4.1 Software

The test program is written within the program processing 3 [10]. Processing can be downloaded for free from their website [10], has a simple way of communicating with the arduino and is able to write data in an excel (.CSV) file which makes the data storage and analysis much easier. This choice of software helps to acquire already two of the four requirements.

Ten paths are created which the user has to follow. The first 5 path's are unique while the second 5 are the same as the first five but than mirrored across the x or y axis. The first five paths all start at the left while the second five start at the right. This way the user is tested with feedback in every direction and can a comparison been made between feedback going to the left or right and feedback going up or down, while the difficulty of the path stays the same. The paths exist of a few points which have to be hit by the user to go to the next point. The paths chosen with their points are given in appendix C.

The points used in the paths are hard coded in a two dimensional array. If the mouse of the user is close to the point, it is accepted and the feedback will point to the next point. The feedback will always point from the current point of the mouse towards the desired endpoint. This way the user is corrected stronger if he/she goes in the wrong direction. The angle and amplitude are calculated and scaled such that the angle is always a multiple of 15 degrees and the amplitude is $\sqrt{8}$ at its maximum, these are used to deliver the feedback to the user. The program calculates an error when the user moves to far out of the path between the previous and next point. When the angle between the previous point and the mouse is bigger or smaller then the angle between the previous and next point the error is calculated by multiplying the angle by which it is out of direction and the amplitude. This way the error increases faster when the user is further off

track. All errors are summed which give the end result of the preciseness of the users handling and thus about the quality of the feedback. This is done with the function "*calcError*" as can be seen in appendix D. Each tenth of a second are the x and y location of the user stored in a table. In the end this table is converted to a excel (.CSV) file. This makes it possible to reconstruct the path of the user by plotting the x and y values. This path can then be compared with the path which was predefined and the paths of the different kind of feedback.

3.4.2 Connecting the skin stretch actuator

The arduino which controls the actuators can calculated the desired position of each servo if it has the desired angle and amplitude of the end effector. Since these both can be calculated out of the current mouse position and the desired end position this can be implemented rather easily. Function "*calcAnAm*" (see appendix D) first calculates the delta x and y between the two points after which it uses the pythagorean theorem to calculated the amplitude. With the use of the inverse tangent the angle is calculated after which it is rounded to a multiple of 15 degrees. Both are communicated to the arduino in the following form, when for example the angle is 180 degrees and the amplitude is 1,2 cm is this communicated as "180|120". The separation mark "|" indicates the end of the angle and the beginning of the amplitude value.

3.4.3 Visual feedback

To compare the results of the haptic feedback a visual feedback is implemented as well. This one works exactly the same as the skin stretch feedback but now is the end effector a small dot in a circle instead of a moving end effector attached to the skin, as depicted in figure 3.5. The point moves in the direction the mouse should do as well, which means in figure 3.5 the mouse should move to the right. When it moves further from the middle the user is further away from the desired end point. The visual feedback is chosen to be this way because the only difference on the quality of the feedback should be the communication method to the user. When something else influences this the results are less valuable. The visual feedback is provided with the function "*calcVisual*" see appendix D. The function simply draws the circle and the middle point, after which the moving point is just a down scaled version of the actual difference in x and y direction of the mouse and desired end point.



Figure 3.5: Visual feedback of the test setup.

4 Experiment

The structural design, circuitry and test setup are theoretically complete. The only step left is to actually create the design, connect it to the test setup and validate the requirements. After this the system should be ready to use and can it be tested to see the impact of it.

4.1 Realization of structural design

As it turned out after 3D printing was the structure well designed. The actuators fit gaps as well as the wheels on the servo motors and the screws which hold everything together. It was not sure if the structure would be strong enough and would not bend because of the great gape beneath the base. The base turned out to be very strong and not bend at all. Which means the walls and roof are chosen big enough and might even be smaller if this is desired. The wires fit within the gaps of the end effector and are also easily connected with a screw to the wheel. The system is validated with the requirements given in chapter 3, which are here listed below as well.

- 1. End effector must be able to move in 24 different directions, each separated by 15 degrees.
- 2. End effector must have a controllable distance from the center.
- 3. System must work independently of teleoperation system.
- 4. System should be lightweight.
- 5. System should be compact.

For the first requirement is the end effector send to multiple different locations in order to see its movements. The arduino calculated the angles of the servo motors correctly and moved the end effector rapidly to the correct location. Which means this requirement is met. With this is immediately the second requirement fulfilled, since the end effector was send to different locations which also had different amplitudes. The system is designed to work on an arduino uno. The communication towards it can be done in many ways (even wireless) therefore can the system be used for any purpose independently of the teleoperation system. As can be seen in figure 4.1 is the system compact enough to fit on the hand, or upper/lower arm if desired. The total weight of the structure equals 127 grams which makes it easily wearable.

4.2 Test setup implementation

As the structural design works as desired and the circuitry does as well since the end effector was able to move to the desired angle with the desired amplitude, is the design connected to the test setup software. In first instance the end effector did not move or try to move at all. This because the feedback was send with 60 Hz, overloading the connection between the computer and the arduino. In order to prevent this and give the servo motors enough time to reach the destination is a counter build in. The counter makes sure the feedback is updated two seconds. This works properly and the motors have indeed enough time to reach their final value and move the end effector to the right position. The software had some requirements as well, which are given in section 3.4.1 and are listed below in the same way.

- 1. Software should create a path which the user has to follow.
- 2. The test setup should test visual feedback, haptic feedback and the combination of both.
- 3. Software should communicate the right angle and amplitude to the arduino.

4. The path of the user has to be stored.



Figure 4.1: The structural design placed on a hand.

The software creates the path properly. One problem occurred when the x and y coordinates where initialized. When x and y are both set to zero the point is in the upper left corner, and when x and y are set to the width and height (900 by 900) the point occurs in the corner down right. Therefore seemed all paths flipped across the x axis. This was easily solved by changing the coordinates from its original value to 900 minus the original value. The path is created and the points hidden, only the previous point is visible in order to prevent the user from seeing the path and guessing where the next point should be. Therefore is this requirement met. A test case is done where the user can get familiar with both types of feedback. After this are the first trials done with visual feedback, then the haptic feedback and finally both simultaneously. Every case works as desired and the program switches easily between the different feedback types, with which it fulfills the requirement. In order to test the angle and amplitude communicated to the arduino is the structural design placed on a glass table. The mouse is moved deliberately around the desired point to see if the end effector moves in the right direction. This is indeed the case which makes the system fulfill this requirement as well. The last requirement is tested by doing the whole test after which the document created is opened and the data is plotted. The plots give the path which the mouse has made. Therefore it can be said that the software written works as desired and therefore the total system. The system is ready to use to test the usefulness of the skin stretch feedback.

4.3 Test setup improvements

After the first few trials it became clear that the structural design needed some adjustments. The amplitude variation was not noticeable at all. People could not distinguish the direction when the amplitude was lower than 50 mm. When increasing the amplitude people did not feel enough change to identify when the amplitude was high or low. The only few cases people where able to distinguish the variation was when the variation was more than 60 millimeters which made it almost impossible to use it. Therefore it was chosen to let the amplitude variation out.

Also the directional feedback was difficult to use. Since the skin was constantly stretched

people get used to the tension and after a few seconds they did not know which direction they should move. Therefor it was chosen to change the directional feedback to pulses. Each two seconds the end effector would move in the right direction, stay there for a second, move back and wait for the next direction to move in. This worked better since people started to recognize the directions in which the feedback moved. A disadvantage of it was when the end effector moved back people tended to move in this direction as well. Which is exactly the opposite direction of which they should actually move. Therefore is a new method applied. Where the end effector first moves slowly towards the direction in which the user should move the mouse after which it gets fast back to the middle point. This way users could distinguish the movement in the right direction and when the end effector was going back. This worked better since people could sometimes follow parts of the path, nevertheless where people sometimes left in the dark.

Because it took people a long time finishing a path with the haptic feedback it is chosen to lower the amount of paths which the user has to make. First the user should make ten different paths, this is lowered to two paths. The used paths are the first two of appendix C and given below in figure 4.2 as well.



Figure 4.2: The paths to be drawn, first and second path of appendix C.

5 Testing

After the participant have signed the informed consent, see appendix E, they are asked to draw the given paths. As mentioned before in 3.4.1 has each participants two test cases in order to get familiar with the soft and hardware. People are able to train them selves here. It is possible to close your eves to ignore the visual feedback. This way people are already trained a little with the haptic feedback before the actual test starts. The test case starts when the mouse hits the first (visible) dot. Then the visual and haptic feedback guide the user towards the next point. If the location of the next point is reached it becomes visible and the previous point disappears, this to prevent the user from recognizing a path. The feedback guides the user again to the next point until all 8 points of one path are touched. When this is done the new trial can be started by again moving the mouse to the new (visible) start point. When the user has finished the two test cases this way the real test is going to start. These trials work the same as the described test cases, the only thing which changes is the form of feedback. First is the user asked to draw the first and second path with the visual feedback. The visual feedback shows the user which direction he/she has to move. This is done as mention in section 3.4.3 where figure 3.5 means the user has to move to the right. This because the big black dot is at the right of the middle. At the moment the user is done with these two trials the same paths come in again but now the user has to draw them with haptic feedback. The user can again close his/her eyes to focus more on the haptic feedback. Nothing is showed on the screen only the previous point hit by the user. Finally the user draws the same paths again with both kinds of feedback at once. Here the user can chose to trust fully on one of both types of feedback but can also use the combination to be more confident about the direction to move in.

5.1 Subjects

The study included N= 10 participants (40% female, 60% male) between the ages 18-58 (M_{age} = 33.54, SD_{age} = 16.41) who voluntarily participated in the study. The average BMI of the participants was 25.65 (sd_{BMI} = 3.07) influencing the elasticity of the skin. Participants were selected through convenience sampling. The sample only included people with a Dutch nationality. Participants did not have to comply with certain criteria to participate in the study except that the participant should be able to feel stretch applied on their skin, being able to see the visual feedback and move their hand. Participants had to be over 18 years old and be able to fill in an English questionnaire to participate in the study.

5.2 User impression

The subjects are asked to fill in a questionnaire after they have done the test. This includes demographic questions (age, gender and BMI) and questions about the usage of the system. The questionnaire can give insight in the reason behind certain results. This will give more insight in how well the system works and how comfortable it is. Besides can it be used for improvements of the system. The whole questionnaire and the possible answers can be found in appendix F

6 Results

In order to answer the question if haptic skin stretch feedback is a helpful tool to control an endoscope, the paths which are created by the users with skin stretch feedback are compared with the paths created with visual feedback and with both kinds of feedback. All paths created by the participants are given in appendix G.

Each participant tried to create the first and second paths of appendix C three times. Once with visual feedback, once with haptic feedback and once with both kind of feedback.

It can be seen that some people had a hard time following the path with the haptic feedback, appendix G. Participant 7 is one of those for example, figure 6.1 shows the paths made by this participant for path 1. With the visual feedback the user was able to stay close to the desired path. Only a few strange hick-ups can be seen for example around x = 200 and x = 600. With the haptic feedback the participant moved in almost any direction touching almost every point on the screen. This indicates clearly that the directions of the haptic feedback where difficult to distinguish for this person. Nevertheless can it be seen that in the last case the path of the user is more smooth compared to visual feedback only. With the second path the same result



Figure 6.1: Paths created by participant 7, trying to follow the first path with visual (left), haptic (middle) and both kinds of feedback (right).

showed. Figure 6.2, shows the result of the second path of participant seven. Indication again he/she had a hard time following the correct path with haptic feedback, but being more secure when both are used. Even though there seems to be a small improvement in the usage of the haptic feedback. There even is a slanted line from x = 200, y = 100 to x = 500, y = 300 following the right direction.



Figure 6.2: Paths created by participant 7, trying to follow the second path with visual (left), haptic (middle) and both kinds of feedback (right).

Appendix G shows that more people drew smoother lines with both kinds of feedback compared to visual feedback only, while the haptic feedback only did not show a clear path. Examples are participant number; 2, 6 and 9. Figure 6.3, shows the results of participant 2. These are highlighted since it can be seen clearly that a participant is able to improve him/herself with the haptic feedback. As the tests where done people mentioned they where learning while drawing the paths. Figure 6.3 shows that while the result of the visual path stays nearly the same the participant clearly improves in the haptic and combination of both kinds of feedback. As almost no path can be distinguished in the first path with haptic feedback, can it be done in the upper right part with the second path.



Figure 6.3: Paths created by participant 2, for the first and second path.

Participant 5 and 8 drew much better paths compared to all the other participants. The paths of participant 5 are shown in figure 6.4. Both paths can be recognized in all kinds of feedback. The haptic feedback paths are clearly better compared with others, nevertheless is this participant no other than the rest. The same holds for this participant, he/she draws better/more secure with both kinds of feedback and he/she improves the haptic feedback (since the second path is better) while doing the test.



Figure 6.4: Paths created by participant 5, for the first and second path.

The second statement is different for participant 8, see figure 6.5. As can be seen in the second path with haptic feedback of the participant has he/she more struggle in the middle of the path. This is not strange since this user moves more in the x or y direction with straight lines, indication even more that he/she has difficulty distinguishing different directions than straight



Figure 6.5: Paths created by participant 8, for the first and second path.

up/down or left/right. The first statement still holds for this participant as the paths with both kind of feedback are still better compared to visual only.

The impression of the users is given in table 6.1. As can be seen have people different opinions about the system, if it is intuitive or not, easy to use or the speed with which people can learn it. Most of the people think they need more training which is supported by the data of the test case as well. The visual feedback and the combination of both are felt as the best options. Where visual only is felt slightly better than the combination of both while the paths show that it is the other way around. People where well isolated during the test, this is important since people can focus better this way on the feedback. Some people felt tired some did not at all, therefor is the mean 3.00 but is the variance 1.24 which is high.

Finally is the calculated error and the time plotted against each other. The result is given in figure 6.6. In general it can be seen that within the visual feedback the error stays much lower compared to the haptic feedback. When both feedback types are used it can be seen that most of the points are in an even lower range than with the visual feedback. Where the visual feedback has still a few errors between ten thousand and twenty thousand, are there only two points in this range when both kinds of feedback are used. Where with the haptic feedback a relation could be seen with increasing time goes increasing error, is this harder to imagine with the other two options.

Since the previous results showed improvement with the second path using haptic feedback compared to the first path and users thought more training would work, are also the error of the first en second haptic feedback drawn paths depicted. In figure 6.7 it can be seen that the errors of the second path are closer to each other and in average lower than those of the first path.

Question	Mean	Standard
	answer	deviation
		answer
The system was intuitive	3.08	1.21
The system was easy to use,	3.15	0.95
I needed support by the test administrator to be able to use the	2.69	1.38
system,		
Most people would quickly learn how to use the system,	3.23	1.19
I felt confident using the system,	2.31	0.99
I needed more training to confidently use the system,	4.38	0.92
Sound from the device caused disturbance while performing	2.31	1.38
the experiments,		
I was well-isolated from external influences,	4.15	1.10
At the end of the experiment I felt tired,	3.00	1.24
The visual feedback gave a good representation of in which dir-	4.62	0.62
ection I had to move,		
With the visual feedback I performed the best,	4.77	0.42
The haptic feedback gave a good representation of in which dir-	2.69	0.99
ection I had to move,		
With the haptic feedback I performed the best,	1.31	0.46
The combination of both kinds of feedback gave a good repres-	4.08	1.07
entation of in which direction I had to move,		
With the visual and haptic feedback I performed the best,	4.15	1.10

Table 6.1: Questionnaire of impression of participants.



Figure 6.6: Error calculated against the time used to complete the path.



Figure 6.7: Error versus time used to complete the first and second path with haptic feedback.

7 Conclusion

The results in appendix G show that people had a hard time creating the correct path with haptic feedback. An easy conclusion would be that it is not useful at all. Nevertheless would this ignoring the real message in the results. As was depicted where some people able to improve them selves. There where even examples of people who had evolved during the test case and drew an rather astonishing path the second time. In the impression questionnaire the participants agreed on needing more training. Meaning they also believe in the fact they could get used to the system even more. Finally are the error and time plots given of the first and second path with haptic feedback which showed an improvement as well. Therefor can it be concluded that unless that people sometimes have a hard time figuring out which direction to move in it is possible to improve yourself by training, which leads to better results. How much training is needed per person and on which variables the amount of training depends has to be found out with more research.

The questionnaire showed that participants found the visual feedback a little better than combination of both. Which is in contradiction with the improvements people showed in drawing their paths with both types of feedback compared to visual and haptic feedback used separately. As is shown with figure 6.1, and can be seen with more cases in appendix G. Also the error comparison done with figure 6.6 showed that people give in general better results when both feedback's are combined. Therefor can it be concluded that people stay better within the path when both types of feedback are used simultaneously, even though people do not recognize this.

Finally can the ultimate question been answered. "Is skin stretch a helpful feedback in order to control an endoscope?" As was stated is this compared with visual feedback and the combination of both. It is compared along the paths created by the user, the impressions of the participants them selves and the calculated error. The paths showed as mentioned that the participant is more likely to move in the wrong direction with haptic feedback only. On the other hand as is shown with the paths, impression and error after which it is concluded that people are able to improve. This leads to, as shown in figure 6.4 and 6.5, paths with almost the same quality as visual feedback only. After which it was shown and concluded that the combination of both worked even better than one of the two feedback's separately, even for not well evolved participants. Therefor can it be concluded that indeed skin stretch can be a helpful tool in order to control an endoscope. It has to be mentioned that as stand alone it is not helpful in the way it is constructed and implemented in this research, but in combination with visual feedback it is an helpful tool.

8 Discussion

The research consists of two parts, the design of the skin stretch actuator and testing the influence of skin stretch applied to the human skin with this design. Since both are done was less time spend on validating the design. The requirements are met and therefore does the system what it is supposed to do. On the other hand is it never tested if it is able to move the given 0,13 mm in section 2.3.1. If this was not the case the design needs to be improved. As well as the accuracy of the angles which the system makes. These are never validated since it was more important to move on and test it with the participants. If the design of the system and testing the influence of it would be separated both can be done with more detail. This would give even more information about the system and what the best method might be to apply skin stretch. Since the research started with the design of the haptic feedback system there was no option to compare different skin stretch methods. If this was desired many more different systems had to be designed which would be very time consuming. Nevertheless would this have been interesting and could give it a lot if insight in what has the most influence on the skin and which is the best noticeable. Then the question if it can be used for the teleoperation system could be answered even better. Therefore is more research needed in order to create, test and compare

different methods of applying skin stretch feedback. Participants often mentioned improvements which could be made. These are different implementations which can be designed and tested in order to compare the different methods. On of the recommendations for next researches is therefore to place a ball on the hand. The ball needs a rough surface, like rubber, to move the skin. With different actuators place close to the upper side of the ball, could small wheels turn the ball in different directions. This would move even more skin than the currently applied method and this way increase the possibility of participants successfully distinguishing the directions. For further research is it also recommended to split the design from the testing. When this is done the design can be validated better and improved further more easily. The testing can be done in a different research where it is in that case possible to test multiple different designs with more people. Which would result in more insight and therefore more and faster development of the haptic feedback. When the haptic feedback is developed more after more research is done the risk of penetrating fragile parts within the body can be decreased which will make the teleoperation safer.

A Appendix

```
const double pi = 3.14159265359;
                                            //insert pi
const double distance = 2.0; //Distance between side and midle of moving space
String angleIn; //Input of the serial connection
double S0_dist = 0.0, S1_dist = 0.0, S2_dist = 0.0, S3_dist = 0.0; //Moving distance
int an_s0 = 0, an_s1 = 0, an_s2 = 0, an_s3 = 0; //Angles of each servo to move
double ampl = 1.0, angle = 0.0;
#include <Servo.h>
Servo s0, s1, s2, s3;
int z0 = 80, z1 = 90, z2 = 120, z3 = 90; //Zero positions
void setup() {
  Serial.begin(115200);
  s0.attach(4);
                 // servo 0 attached to pin 4 y
  sl.attach(5);
                  // servo 1 attached to pin 5 g
  s2.attach(6); // servo 2 attached to pin 6 w
  s3.attach(7);
                  // servo 3 attached to pin 7 b
  s0.write(z0);
                             // tell servo to go to the starting position
  s1.write(z1);
  s2.write(z2);
  s3.write(z3);
}
void loop() {
  if (Serial.available() > 0) { //Check for data on the serial port
    angleIn = Serial.readString(); //Read string of serial port
      angle = pi / 180.0 * angleIn.toInt(); //convert angle to radial
      //calculate dx and dy
      double dx = ampl * cos(angle);
      double dy = ampl * sin(angle);
      //Use pythagoras to calculate the desired wire length
      S0_dist = sqrt(pow((distance - dx), 2) + pow(dy, 2));
      S1_dist = sqrt(pow(dx, 2) + pow((distance - dy), 2));
      S2_dist = sqrt(pow((distance + dx), 2) + pow(dy, 2));
      S3_dist = sqrt(pow(dx, 2) + pow((distance + dy), 2));
```

```
//Use the wire length to get the desired angle.
      an_s0 = round(((S0_dist - 2) / 2) * 90 + z0);
      an_s1 = round(((S1_dist - 2) / 2) * 90 + z1);
      an_s2 = round(((S2_dist - 2) / 2) * 90 + z2);
      an_s3 = round(((S3_dist - 2) / 2) * 90 + z3);
      //Average middle value with desired value
      //Where middle value importance decreases and desired increases
      int steps = 20;
      for ( int i = 1; i \le steps; i + +){
        s0.write((((steps-i)*z0)+(i*an_s0))/steps);
        s1.write((((steps-i)*z1)+(i*an_s1))/steps);
        s2.write((((steps-i)*z2)+(i*an_s2))/steps);
        s3.write((((steps-i)*z3)+(i*an_s3))/steps);
        delay(600/steps);
      }
         delay(400);
      // Move servo back to the middle
      s0.write(z0);
      s1.write(z1);
      s2.write(z2);
      s3.write(z3);
    }
}
```

B Appendix



Figure B.1: Dimensions of the base (seen from below).



Figure B.2: Dimensions of the head.





C Appendix



Figure C.1: Programmed paths, left column starts left going right, right column starts right going left.

D Appendix

//The user has to foow a certain line by connecting the dots with its mouse. //The dots are not visible, the visual feedback or haptic //skin stretch feedback shall guide the user towards the point. //Lines are pre defined in matrixes. //First a testcase is done, after that is first only visual feedback used, //then skin stretch feedback and lastly both simultaniously. //Finaly are the error and time score shown. //Error is calculated when the user is to far out of the path //he/she should follow, by multiplying the angle with the amplitude of the error. //Created by Christian Ewout Baars (Student number s1704532) //In order of RAM (Robotics And Mechatronics) //University of Twente. //30-06-2018 import processing.serial.*; //Library for serial connectionSerial port; Serial port; String name = "participant_1"; //Test amount/tests counter/ maximum points per test / Current point in test int testAmount = 30, testCnt = 0, pointMax = 8, pointCnt = 0; //Minimum amplitude to hit point/ with of path (angle) int space = 4, angleSpace = 15; //Amplitude to previous point/ Amplitude to next point/ //angle to next point/ angle between previous and next point. int ampToPrev = 0, ampOut = 0, angleOut = 0, pointAngle = 0; float pi = 3.14159265359; //insert pi int timer = 0; //time storage int error = 0; //Error storage int[] score = new int[testAmount]; //Score storage int[] timeScore = new int[testAmount]; //Time score storage Table pathStore; int Xplace = 0, Yplace = 0; //X and y of next point int xPrev = 0, yPrev = 0; //X and y of previous point float deltaX =0.0, deltaY = 0.0; //Difference between next point and mouse. //counters used for sample taking int frameCnt= 0, frameFeedback = 120, storeCnt = 0, feedbackCnt = 0; int state = 0; //State switcher

```
PFont font; //font for text display
//Test points, first is y second is x.
int[][] test = {{50, 500, 650, 600, 450, 300, 250, 400, 850},
  \{50, 150, 250, 350, 450, 550, 650, 750, 850\}\};
//Trial x points, 1 row is 1 path
int [][] xPath = {{50, 150, 250, 350, 450, 550, 650, 750, 850},
  \{50, 150, 250, 350, 450, 550, 650, 750, 850\},\
  \{50, 150, 250, 350, 450, 550, 650, 750, 850\},\
  \{50, 150, 250, 350, 450, 550, 650, 750, 850\},\
  \{50, 150, 250, 350, 450, 550, 650, 750, 850\},\
  \{850, 750, 650, 550, 450, 350, 250, 150, 50\},\
  \{850, 750, 650, 550, 450, 350, 250, 150, 50\},\
  \{850, 750, 650, 550, 450, 350, 250, 150, 50\},\
  \{850, 750, 650, 550, 450, 350, 250, 150, 50\},\
  \{850, 750, 650, 550, 450, 350, 250, 150, 50\}
};
//Trial Y points, 1 row is 1 path
int [][] yPath = {{50, 500, 650, 600, 450, 300, 250, 400, 850},
  \{850, 700, 800, 750, 550, 200, 150, 250, 600\},\
  \{100, 500, 650, 750, 800, 750, 650, 500, 100\},\
  \{100, 100, 800, 800, 100, 100, 500, 500, 800\},\
  \{800, 650, 200, 300, 600, 100, 400, 500, 100\},\
  \{50, 500, 650, 600, 450, 300, 250, 400, 850\},\
  \{850, 700, 800, 750, 550, 200, 150, 250, 600\},\
  {800, 400, 250, 150, 100, 150, 250, 400, 800},
  \{100, 100, 800, 800, 100, 100, 500, 500, 800\},\
  \{800, 650, 200, 300, 600, 100, 400, 500, 100\}
};
void setup () {
  //Create frame
  size(900, 900);
  frameRate(60);
  background(244);
  font = createFont("Arial", 30, true); //Create font
  timer = millis();//Start timer
```

```
pathStore = new Table();
  println("Available serial ports:"); //Print the serial ports
  for (int i = 0; i<Serial.list ().length; i++) {</pre>
   print("[" + i + "] ");
   println(Serial.list()[i]);
 }
  port = new Serial(this, Serial.list()[0], 115200);//Make connection to serial port
}
void draw() {
 background(244);
  textFont(font, 30); //Reset font if changed
  fill(0);
//0=start,
//l=testcase ,
//2=prepare for next trial,
//3=do next trial,
//4=done/showscore
  switch(state) {
   //_____Start_____
  case 0:
   text("The test is going to start", 50, 40);
    text("It consists of " + testAmount + " paths", 50, 100);
    text("The feedback will help you", 50, 160);
   Yplace = test[1][pointCnt]; //Set x and y
   Xplace = test[0][pointCnt];
   calcAnAm(); //Calculate angle and amplitude between mouse and next point.
    ellipse(Xplace, Yplace, space, space); //Show point
    if (ampOut<=space) { // If mouse is close to the point start the testcase
     pointCnt+=1;
     state += 1;
     timer = millis(); //reset timer
   }
   break;
   //____Testcase_____
  case 1:
    text("Testcase", width/2-20, 40);
   //Update x and y and delta x and y
```

```
Xplace = test[0][pointCnt];
  Yplace = test[1][pointCnt];
  //Show previous point
  ellipse(test[0][pointCnt-1], test[1][pointCnt-1], space, space); //Show point
  calcAnAm(); // Calculate angle and amplitude between mouse and next point.
  if (ampOut<=space) {//If mouse is close to the point go to next
    pointCnt+=1;
    if (pointCnt>pointMax) { // If all points done, start first trial.
      state +=1;
      timer = millis();
      pointCnt=0;
    }
  } else {
    hapticFeedback(); //Give haptic feedback to user
    calcVisual(); //Show visual feedback
  }
  break;
  //____Start trial___
case 2:
  text("Trial " + testCnt + " is going to start", 50, 40);
  //Update X and Y
  if (testCnt< testAmount/3) { // Visual trials
    Yplace = yPath[testCnt][pointCnt];
    Xplace = xPath[testCnt][pointCnt];
  } else if (testCnt < testAmount*2/3) { // Haptic trials</pre>
    Yplace = yPath[testCnt-testAmount/3][pointCnt];
    Xplace = xPath[testCnt-testAmount/3][pointCnt];
  } else {
                       //Visual and haptic trials
    Yplace = yPath[testCnt-testAmount*2/3][pointCnt];
    Xplace = xPath[testCnt-testAmount*2/3][pointCnt];
  }
  calcAnAm();//Calculate angle and amplitude between mouse and next point.
  ellipse(Xplace, Yplace, space, space); //Draw start point
  if (ampOut<=space) { // if Mouse is at start point,
    pointCnt+=1;
                          //increase point
    state += 1;
                          //Start trial
    pathStore.addColumn("x"+testCnt); //Create storage room
```

```
pathStore.addColumn("y" +testCnt);
   timer = millis();
                                 //Reset timer
   error = 0;
                             //Reset error
 }
 break;
 //____Do trial_____
case 3:
 text("Trial " + testCnt, 50, 40);
 //Update x and y for different cases.
 //when visual feedback is active caclVisual will show the feedback
  if (testCnt< testAmount) {</pre>
   if (testCnt<testAmount/3) {</pre>
                                    //Visual feedback
     updateXY(testCnt, pointCnt);
     showPath(testCnt, pointCnt);
     calcVisual();
   } else if (testCnt < testAmount*2/3) { //Skinstretch feedback</pre>
     updateXY(testCnt-testAmount/3, pointCnt);
     showPath(testCnt-testAmount/3, pointCnt);
     hapticFeedback(); //Give haptic feedback to user
   } else {
                                              //Both
     updateXY(testCnt-testAmount*2/3, pointCnt);
     showPath(testCnt-testAmount*2/3, pointCnt);
     hapticFeedback(); //Give haptic feedback to user
     calcVisual();
   }
   if (ampOut<=space) { //When the point is hit, go to next
     pointCnt+=1;
     if (pointCnt>pointMax) { //When this was the last point:
       score[testCnt] = error; //Store score
       state -= 1;
                                 //Go to start of trial
       timeScore[testCnt] = millis() - timer;
                                               //Store time score
                                             //Reset timer
       timer = millis();
       testCnt +=1;
       pointCnt=0;
                         //Reset variables
       storeCnt = 0;
       frameCnt = 0;
       feedbackCnt = 0;
     }
   } else {
```

```
storeDate();
      }
    }
    if (testCnt>= testAmount) { //When the last test is done
      pathStore.addColumn("error"); //Store error and time
      pathStore.addColumn("time");
      for (int i = 0; i<testAmount; i++) {</pre>
        pathStore.setInt(i, "error", score[i]);
        pathStore.setInt(i, "time", timeScore[i]);
      }
      saveTable(pathStore, "data/" + name + ".csv");//Save all data to excel
    }
    calcError(); //Calculate the error if needed
    break;
    //____Finish___
  case 4:
    text ("Thank you the test is done, your score:", 50, 40);
    textFont(font, 20);
    for (int i = 0; i<testAmount; i++) { //Show time and error score</pre>
      text("test " + i, 50, 70+20*i);
      text("Time " + timeScore[i] + " ms ", 200, 70+20*i);
      text("Error " + score[i], 400, 70+20*i);
    }
    break;
  }
}
void mouseClicked() { //Update haptic feedback if mouse is clicked
  if (testCnt>=testAmount/3||state == 1) {
    port.write(str(angleOut));
 }
}
void hapticFeedback() {
  feedbackCnt+=1; //increase counter
```

```
if (feedbackCnt == frameFeedback) { //when 2 seconds have past
    feedbackCnt =0;
                                      //reset counter
    port.write(str(angleOut));
                                     //Give haptic feedback
  }
}
void storeDate() {
  frameCnt+=1; //Framecounter increment
  if (frameCnt== 6) { //Each 6 frames data is stored
    if (pathStore.getRowCount()<=storeCnt) { //Check if row is available</pre>
      pathStore.addRow();
    }
    storeCnt+=1;
    pathStore.setInt(storeCnt-1, "x"+testCnt, mouseX); //Store data
    pathStore.setInt(storeCnt-1, "y"+testCnt, mouseY);
    frameCnt = 0;
 }
}
void updateXY(int row, int col) {
  //Updates the X and Y of the next and previous point
  Yplace = yPath[row][col];
  yPrev = yPath[row][col-1];
 Xplace = xPath[row][col];
  xPrev = xPath[row][col-1];
 calcAnAm();
}
void calcVisual() {
  //Shows the visual feedback
  ellipse (width/2, height/2, 205, 205);//Draw black ellipse (for edge of circle)
  fill(244);
  ellipse (width/2, height/2, 200, 200); //Draw smaller ellipse with background collor
  fill(0);
  ellipse(width/2, height/2, 2, 2); //Center point
  //Moving feedback point
  ellipse((width/2)+(deltaX*-100/width), (height/2)+(deltaY*100/height), 10, 10);
}
void calcAnAm() {
  //Calculates all values needed for haptic feedback and error calculations.
```

```
//Distance between mouse and next point
  deltaX = mouseX - Xplace;
  deltaY = Yplace - mouseY;
  //uses pythagoras to calculate amplitude to previous point and next point
  //Is scaled beteen 0 and 141, since these are the min and max amplitude
  double pytha = sqrt(pow(deltaX, 2)+pow(deltaY, 2)); //calculate hypotenus
  ampOut = round(((pytha)/(sqrt(pow(width, 2)+pow(height, 2))))*141); // scale
  pytha = sqrt(pow(mouseX-xPrev, 2)+pow(mouseY-yPrev, 2)) //calculate hypotenus
  ampToPrev = round(((pytha)/(sqrt(pow(width, 2)+pow(height, 2))))*141); //scale
  //Calculates angle between mouse and next point
  //is zero when point is on the right of the mouse
  angleOut = round( atan(deltaY/deltaX)*180.0/pi);
  //Add's 180 or 360 when needed since atan is only between 0 and a half pi
  if (mouseX>= Xplace) {
    angleOut +=180;
  } else if (mouseX<=Xplace & mouseY<=Yplace) {</pre>
    angleOut+=360;
  }
  //Scales angle to one of the 24 different positions.
  //Rounded to the nearest.
  if (angleOut%15>7) {
    angleOut = angleOut + 15 - angleOut%15;
  } else {
    angleOut = angleOut - angleOut%15;
  }
  if (angleOut==360) {
    angleOut =0;
  }
};
//Shows previous point
void showPath(int test, int num) {
  // for (int i = 0; i < num; i++) {
  ellipse(xPath[test][num-1], yPath[test][num-1], space, space);
  11 }
}
void calcError() {
```

```
//Calculates and sums the error of current trial
  //Angle between previous and next point.
  pointAngle = round( atan((Yplace-yPrev)/(xPrev-Xplace))*180.0/pi);
  //Add's 180 or 360 when needed since atan is only between 0 and a half pi
  if (xPrev>= Xplace) {
    pointAngle +=180;
  } else if (xPrev<=Xplace & yPrev<=Yplace) {</pre>
    pointAngle+=360;
  }
  //When the amplitude of the mouse is to far away of previous and next point
  //and it went not in the right direction (angle, with some space)
  //The error is calculated and summed up.
  if (ampOut>space&ampToPrev>space&angleSpace<abs(pointAngle-angleOut)%(360-space))
    error+= ampOut *angleOut/100;
  }
}
```

E Appendix

___-06-2018

Haptic feedback using skin stretch

You are being invited to participate in a research study which is concerned with improving the performance during endoscopic investigation, using haptic feedback. This study is part of a bachelor thesis, conducted by Ewout Baars from the RAM department at the University of Twente.

During the study, you will be asked to perform a small test and afterward fill in a short questionnaire about your experiences during the performance of this test.

There are no known risks involved while participating in this study. The information you provide during this test, will exclusively be used to help me understand more about the usability of haptic feedback in general, will be treated confidential. The test will take approximately 15-20 minutes of your time.

Your participation in this study is completely voluntarily. During the test it is possible to withdraw at any time without any consequences. The results of the test will stay anonymous.

If you have any questions concerning the study, you may contact me at;

c.e.baars@student.utwente.nl

Informed consent

"I hereby declare that I have read and understood the provided information and have been informed in <u>a_mannet in which</u> the nature and method of the study is clarified. I understand that my participation is anonymous and on voluntary basis and I am free to withdraw from the study at any time without giving a reason or without any costs."

0	l agree
0	l disagree

Name of researcher

Signature

Ewout Baars

Name of participant

Signature

Figure E.1: Informed consent, to be signed for testing.

F Appendix

Table F.1: Q	uestions of	fquestionnaire	with possible	answers.
--------------	-------------	----------------	---------------	----------

Question	I fully dis-				I fully
	agree				agree
The system was intuitive	1	2	3	4	5
The system was easy to use,	1	2	3	4	5
I needed support by the test administrator to be able to use the	1	2	3	4	5
system,					
Most people would quickly learn how to use the system,	1	2	3	4	5
I felt confident using the system,	1	2	3	4	5
I needed more training to confidently use the system,	1	2	3	4	5
Sound from the device caused disturbance while performing	1	2	3	4	5
the experiments,					
I was well-isolated from external influences,	1	2	3	4	5
At the end of the experiment I felt tired,	1	2	3	4	5
The visual feedback gave a good representation of in which	1	2	3	4	5
direction I had to move,					
With the visual feedback I performed the best,	1	2	3	4	5
The haptic feedback gave a good representation of in which	1	2	3	4	5
direction I had to move,					
With the haptic feedback I performed the best,	1	2	3	4	5
With the visual and haptic feedback I performed the best,	1	2	3	4	5
The combination of both kinds of feedback gave a good rep-	1	2	3	4	5
resentation of in which direction I had to move,					
What is your age?					

What is your BMI?

G Appendix



Figure G.1: Results of test with the first path, Left column with visual feedback, middle with haptic, right with both.



Figure G.2: Results of test with the second path, Left column with visual feedback, middle with haptic, right with both.

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