University of Twente

Master Technical Medicine

M3 internship

A clinical trial performed to analyze and to reproduce upper body movements during (upper GI) flexible endoscopy for the purpose of developing a serious game

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Abstract

Aim: The traditional way of teaching a resident is education in a clinical setting from a supervisor. However, since the time a surgeon has to train a resident is reduced and training should be in a cost-effective manner, new ways of teaching should be developed. The goal of this study is to develop a new way to teach novices endoscopic skills by means of a serious game. The game will focus on navigating with the endoscope through the game, reproducing the psychomotor skills required for the performance of a good endoscopic procedure.

Method: The movement of the endoscopist will be measured by means of the Xsens motion tracking system and the endoscope will be tracked by the NDI Aurora tracking system during a diagnostic gastroscopy. The procedure will be performed on a porcine model, a silicone model and in the clinical setting. The movement of the left hand, sternum movement, smoothness of movement and procedure time of the endoscopist will be compared between novices and experts. The measured Xsens data will be used to animate the experts movement in the simulation part of the serious game. The BN055 IMU sensor together with the Aurora tracking system will be used for implementation of movement of the endoscope inside the game part of the serious game.

Results: The experts move their left hand more gradually and controlled compared to the novices, there is also more controlled torque of the endoscope shaft compared to the novices, which could result in less patient discomfort. When the porcine and silicone model are compared to the clinical trial setting, there are differences in the left hand movement. The recorded data can be used for a simulation of the procedure, however, the Xsens suit is giving more information then can be implemented into the physical endoscope for the game part of the serious game. Measuring the BN055 IMU sensor to the scope handle combined with the Aurora tracking sensor can be directly translated into the game part of the serious game.

Conclusion: The clinical trial measurements shows a different movement of the left hand compared to both the models. To make the simulation more realistic, clinical trial measurements are of importance. The upper body movements can be recorded and reconstructed in a simulation showing the novice how to move. However, for the game part, the movement of the endoscope handle relative to the endoscope shaft are important. No clinical trial measurement is needed for implementation in the game part of the serious game.

Keywords: Aurora, NDI, Xsens, Electromagnetic tracking, Serious game, Endoscopy

Contents

1 General introduction

The traditional way of teaching a resident is education in a clinical setting from a supervisor. However, since the time a surgeon has to train a resident is reduced and training should be in a cost-effective manner, new ways of teaching should be developed. Also patient safety limits the possibilities for residents to train on everyday cases.[1,2] Simulations and serious games could fill this educational gap, so the resident can optimize the educational time in the operation room (OR). The time spent on a simulator is positively linked to the clinical quality of the procedures[3,4,5,6,7]. The lack of enthusiasm of surgeons for flexible endoscopy also results in a deficit in training residents flexible endoscopic skills[8]. The game element in a serious game might be a solution for this problem[9,10]. Ali et al. have shown that if the resident has experience with gaming, the rate in which the resident learns new surgical skills is increased[11]. Skills learned on the simulator are proven to be transferable to the clinical setting[12].

Figure 1: Manipulation possibilities of a flexible endoscope.[13]

In Figure 1, the different manipulations of the endoscope are shown. Turning of the wheels will be executed with the left hand of the endoscopist and the wheels control the steering of the distal tip of the endoscope. The tip can move up and down (influenced by the big wheel, movement **a** in Figure 1) and left and right (influenced by the small wheel, movement **b** in Figure 1). The right hand holds the endoscope at the insertion point (point where the endoscope enters the body). The scope can be inserted or retracted from the insertion point (movement **c** in Figure 1). The scope can also be rotated (movement **d** in Figure 1). Torque of the scope can change the movement of the wheels, since rotation could make movement **b** change from left/right to up/down and vice versa for movement **a**.[13]

Virtual simulations can be used to enhance psycho-motor skills competency[1]. Most benefits in learning endoscopy can be achieved when a resident is in his initial learning phase[12,14,15]. The transfer of skills from a simulated situation to a patient-based environment has proven to be achievable[4,5,6,7], and can be learned in a video game setting[11,16]. In a video game the combination between challenge and the learning process can be combined in an enjoyable and didactic way[17]. The competition aspect in a serious game increases voluntary usage[9].

Currently there are several flexible endoscopy simulators available, like the GI MENTOR (Simbionix), EndoSim (surgical science), and ENDOVR (CAE). The downside of these simulators is that they are expensive and bulky, which causes the need to place them in a specific simulation training center to practice.[13] These simulators define an operator experience based on parameters such as; procedure completion time[7,12], required assistance[12], percentage of time of mucosal visualization[14], and path length of the endoscope[18]. In addition to these parameters it would also be interesting to study the upper body movements of the resident practicing the several procedures, since research showed there is a significant difference in posture and movements between experts and novices[19]. Experts and novices will be compared to show that there is a need for novices to learn the correct way of movement during an endoscopic procedure.

Everbusch and Lightdale et al. have demonstrated that psychomotor training has a significant effect on the learning curves of a simulated colonoscopy[20,21,19]. A previous technical medicine student has been working on acquiring a database consisting of movements of expert and novice endoscopists, a so called motion library.[13] In this database the movement of the endoscopist is linked to the movement of the endoscope. For example if the endoscopist is moving his right arm, the scope could move in a forward/backward manner, but also change the orientation of the tip of the endoscope by turning the scope. These measurements were recorded using the Xsens suit (MVN Awinda, Enschede, The Netherlands) and Aurora system (NDI, Waterloo, Canada).

The goal of this study is to develop a new way to teach novices endoscopic skills by means of a serious game. The serious game will give feedback on psychomotor skills during flexible endoscopic maneuvers. The hypothesis is that the acquired data might be helpful in reducing the training time required to achieve sufficient flexible endoscopic skills and better prepare novices before moving to the clinical setting. The game should be low in cost, to provide widespread accessibility.

1.1 Goal of this research

This study is part of the Everest project at IHU (Strasbourg, France), which is established in association with the University of Twente. This study is part of the surgical endoscopy framework in which a low-cost endoscopic simulator will be designed. The aim of the surgical endoscopy framework of the Everest project is to create a low cost serious game, which is easy to use, highly modifiable, and the game must be engaging and fun. The serious game will teach the player basic endoscopic skills. The game will focus on navigating with the endoscope, reproducing the psychomotor skills required for the performance of a good endoscopic procedure.[13]

1.1.1 Research questions

The main research question is:
How can upper body movement measurements be used for psychomotor skill instruction in a serious game?

The main research question is answered by means of the following sub questions:

1. Which movements are relevant during a standard diagnostic gastroscopy and can they be reproduced in a serious game?

2. How does upper body movement differ when performing gastroscopy on silicone stomachs, pig stomach models or human stomachs?

3. Is it possible to synthesize an ideal expert from the expert database?

2 Tracking systems

2.1 Introduction

A technical setup has been made to track the movements performed during the gastroscopy. The setup exists of multiple tracking systems, such as the Xsens (MVN Awinda, Enschede, The Netherlands), which is worn by the endoscopist. The Aurora system (NDI, Waterloo, Canada) is used to track the endoscope, and a wheel tracking system to measure the rotation of the weels, in order to measure the angle of the endoscope tip. A database will be created out of these measurements with the aim of teaching psychomotor skills through a serious game. The setup of all tracking sources is shown in Figure 2 and will be explained below.

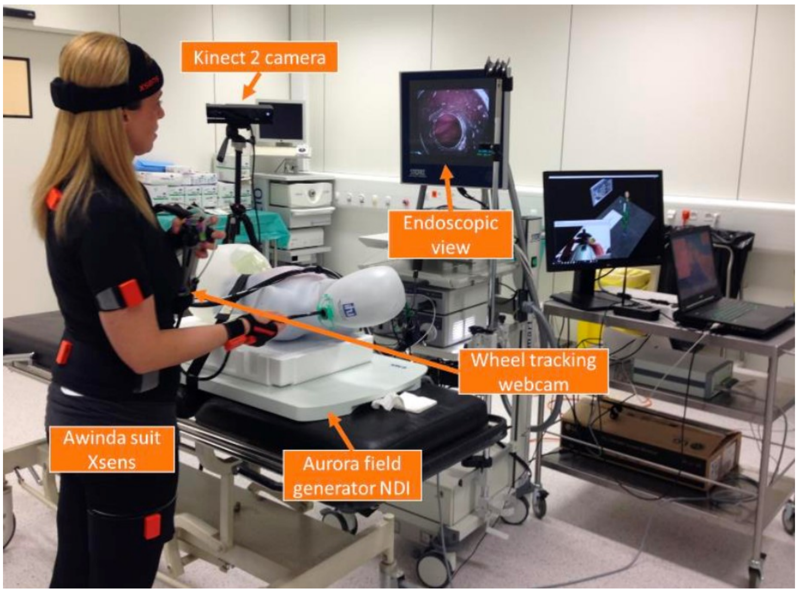

Figure 2: Technical setup with tracking sources

2.2 Xsens motion tracking

To track the body movements from the endoscopist, the MVN Awinda Xsens suit will be used. The suit contains 17 motion trackers (MTw). Each tracker contains linear accelerometers, rate gyroscopes, magnetometers and a barometer. The accelerometer, gyroscope and magnetometer measure in three dimensions.[22] The recorded data is streamed from the suit to the MVN Studio program on a laptop.

The placement of the trackers can be seen in Figure 3. The kinematics are estimated between sensors based on a biomechanical model.[23] The biomechanical model consists of 23 segments: pelvis, L5, L3, T12, T8, neck, head, right and left shoulder, upper arm, fore arm, hand, upper leg, lower leg, foot and toe. This model assumes that the body consists of segments which are connected by joints. The sensors are attached to these segments. Joints origins are determined by the anatomical frame with the use of premeasured body measurements (length of arms, legs, hip length etc.).

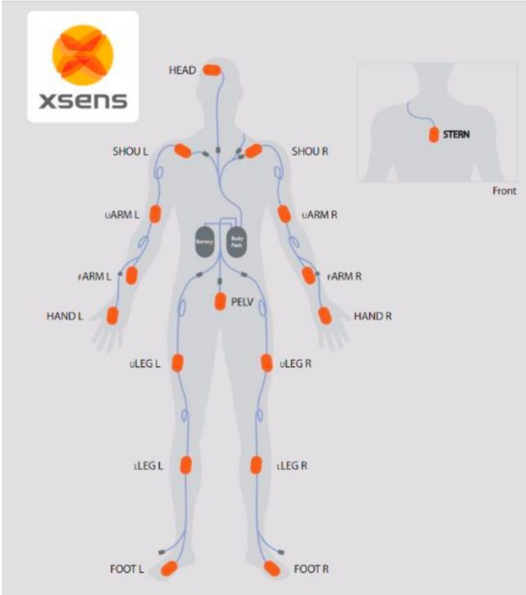

Figure 3: Placement of the Xsens motion trackers

2.3 Aurora probe

The Aurora probe is a 1.20 meter long fibre probe, with seven miniature electromagnetic coils, that can be localized by the Aurora system, the probe is shown in Figure 4. The coils are placed at 15, 115, 256, 415, 565, 715 and 865 mm from the tip of the probe. To track the exact movement of the endoscope, the Aurora probe will be inserted into the working channel of the gastroscope. To keep the probe from rotating or moving within the working channel of the endoscope, it will be fixed with a transparent endoscopy cap at the end. The coils are placed in a varying magnetic field, which enables calculation of the position and orientation of the coils due to an induction of voltages in the coils.[24,25,26] By knowing the position and orientation of the coils, the shaft of the gastroscope can be reconstructed. The magnetic field is generated by a plate (762 mm x 507 mm x 34 mm), which is shown in Figure 5. In Figure 6 the Aurora software is shown, the different coils inside the probe are shown above the magnetic field generator. The colored dots are the different coils and for every coil the position and quaternion position is given.

Figure 4: The Aurora probe used to capture movement of the endoscope

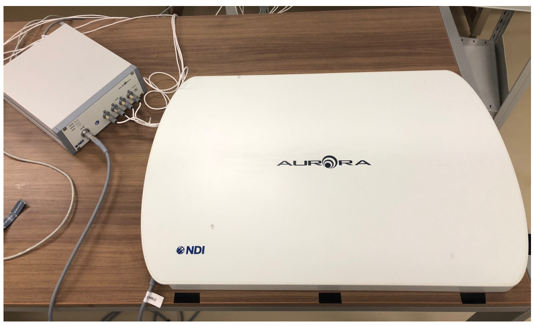

Figure 5: Aurora field generator

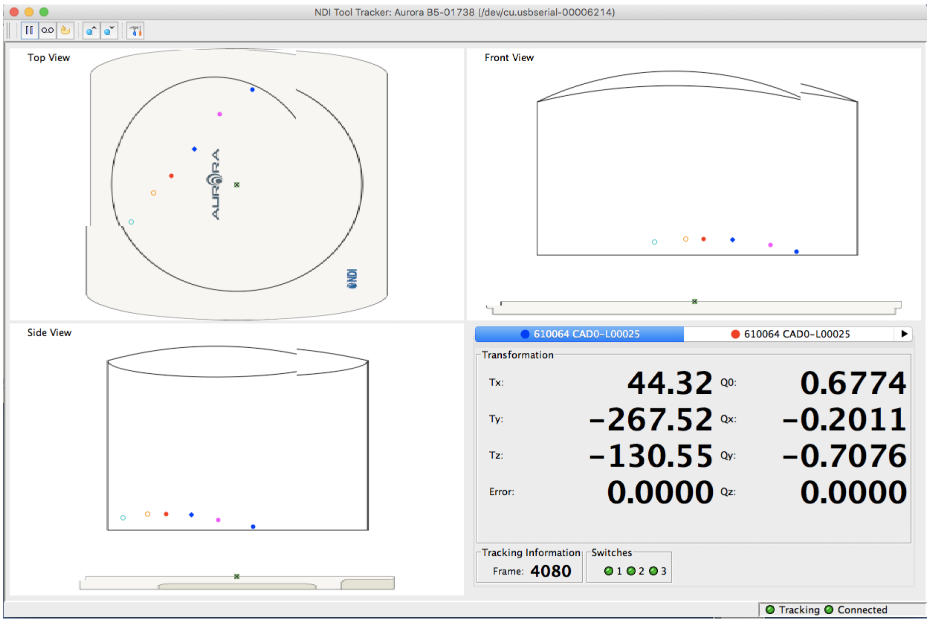

Figure 6: Aurora tracking software

2.4 Wheel tracking system

Due to the impossibility of tracking the wheel motion with the Xsens or the Aurora system, an in-house program was developed. This is an optical tracking system, which is based on a color-coded algorithm. A HD camera will only film the wheels and the algorithm will work based on the colors the camera 'sees'. The color band is shown in Figure 7. When the wheel is rotated, the camera will catch a different color on the video, which results in a known rotation of the wheel. The colors on the band have a maximum difference from one another, based on the HSV color range. The HSV color range is chosen, because it is less prone to be influenced by the light compared to RGB colors. The order of colors is known by the algorithm, so when the physician is covering the color, the system will still know what color should come next and can still determine the wheel angle. The physician has to wear a special color gloves, which is known in the the algorithm. If the physician is wearing a different color gloves, the algorithm might think it is part of a color and an error occurs. As can be seen in Figure 8 the gloves will be masked by a pinkish color, which means the software has correctly segmented the gloves so they will not interfere in calculating the angles. On the wheels a line is drawn, with circles in a certain color. When analyzing the wheel rotation the color of the circle matches with it position on the wheel.

Figure 7: Color band and wheel tracking setup

Figure 8: Post experiment analysis of the wheels

2.5 Data acquisition software

All the recorded data should be synchronized before any further analysis, which is why a C-based software program has been created. The Aurora probe has an update frequency of 15 Hz, the Xsens system 60 Hz, and the external camera updates with 20 Hz. The data is resampled at 20 Hz, with the same timestamp for each source. If it is not possible to get the same timestamp, the nearest one will be chosen. With this software, data of the Aurora can be analyzed relatively to those from the Xsens. The program recording the data can be seen in Figure 9. The first area (1) represents all tracking systems that must be registered before the beginning of the acquisition. To confirm this setup phase, they should all be in green writing. Next to the tracking systems (area 2), the coils of the Aurora are shown in red. When the coils are within the magnetic fiels, a check mark appears. This way all the coils can be checked separately. When recording the different phases of the gastroscopy can be marked and used for later analysis (area 3). The different phases can be seen in the left bottom part of the recorder. When double clicking on the specific phase a time stamp will be shown in area 4 of the program.

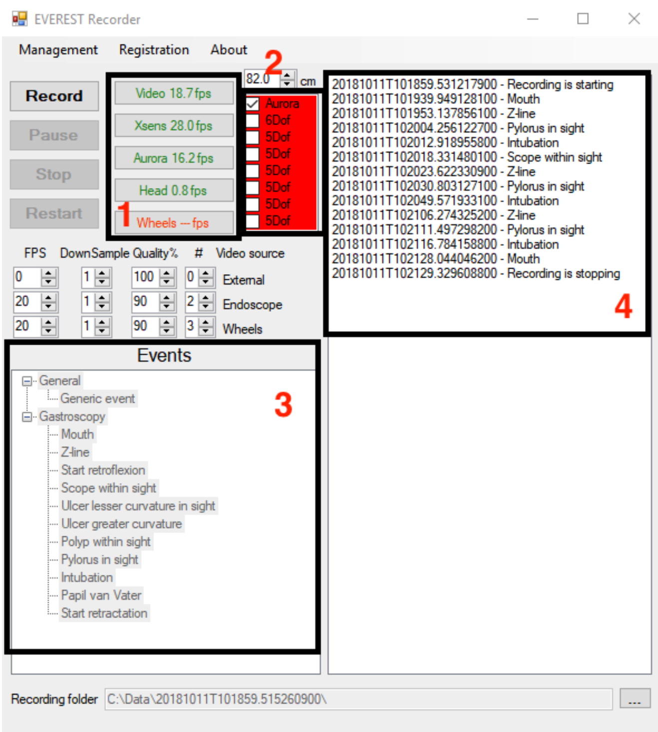

Figure 9: Software to record the data of the Aurora and the Xsens suit

3 Pre-clinical trial

3.1 Introduction

Before the experiment can be performed on patients, a pre-clinical trial is performed to allow participants (experts and novices) become more familiar with the setup. For the pre-clinical trial a silicone stomach will be used inside a mannequin. The aim of the pre-clinical trial is to show differences between novices and experts in a simple endoscopic procedure, namely a diagnostic gastroscopy. The silicone model will be compared to earlier recorded measurements on a pig stomach to validate the silicone model as a realistic stomach model.

3.2 Methods

For the pre-clinical trial a mannequin is used with a silicone stomach, as shown in Figure 10. For comparison in the analysis the earlier recorded data was also used, these measurements were performed on a mannequin with a pig stomach, as shown in Figure 11.

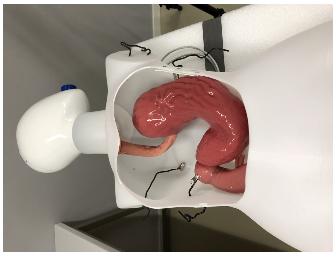

Figure 10: Mannequin with silicone stomach

Figure 11: Mannequin with pig stomach

During the gastroscopy there are a couple of recognition points that can be determined; entering the mouth, the gastroesophageal junction (z-line), start retroflexion, scope within sight, pylorus in sight, entered duodenum, start retraction and mouth, as shown in Figure 12. During the recording these recognition points will be marked.

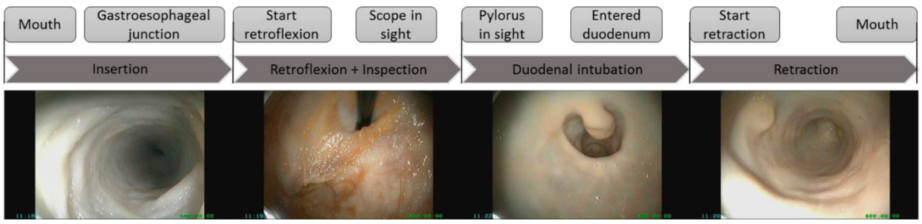

Figure 12: The recognition points and clinical phases

The marked recognition points will be used to identify the different phases of the gastroscopy and to compare the pathlength, procedure time and movement of the upper body between experts and novices. Procedure time is defined as the total time to perform the gastroscopy from mouth to start retraction in seconds. The pathlength is measured in 3D space and can be calculated with:

$$S = \sum_{i=0}^{n} S_i \tag{1}$$

$$S_i = \sqrt{(X_{i+1} - X_i) + (Y_{i+1} - Y_i) + (Z_{i+1} - Z_i)} \tag{2}$$

Where:
S = the pathlength
S_i = the pathlength at i^{th} point
X_i = the X-coordinate at i^{th} point
Y_i = the Y-coordinate at i^{th} point
Z_i = the Z-coordinate at i^{th} point

A metric of smoothness (longitudinal jerk) of the sternum movement is defined as the change in acceleration and can be calculated as followed:

$$V_i = \frac{S_i}{T_{i+1} - T_i} \tag{3}$$

$$V_{i+1} = \frac{S_{i+1}}{T_{i+2} - T_{i+1}} \tag{4}$$

Where:
V_i = velocity at i^{th} point
T_i = time at i^{th} point

$$a_i = \frac{V_{i+1} - V_i}{T_{i+1} - T_i} \tag{5}$$

$$a_{i+1} = \frac{V_{i+2} - V_{i+1}}{T_{i+2} - T_{i+1}} \tag{6}$$

Where:
a_i = longitudinal acceleration at i^{th} point

$$J_i = \frac{a_{i+1} - a_i}{T_{i+1} - T_i} \tag{7}$$

Where:
J_i = longitudinal jerk at i^{th} point

Previously during recordings the camera for the wheel tracking was taped to the endoscope. To get the same distance between the endoscope and the camera for every recording a 3D CAD model was made. This model is shown in Figure 13.

Figure 13: 3D printed model for the HD camera on scope

The movement of the endoscopist will be measured by means of the Xsens suit. Head tracking will be executed by a kinect camera, which can later be used to overlay the Xsens data with the input from the kinect. The movement of the endoscope will be measured with the Aurora probe and field generator. A set-up can be seen in Figure 2. The data of the Xsens will be aligned with the head tracking data of the kinect and the data of the Aurora will be combined with the Xsens in one video and are given the same timestamp, because the data of both the Aurora and the Xsens will be re-sampled at 50 ms. Since the Xsens measures more data per minute than the Aurora, some of the data from the Xsens will be discarded.

Analysis of the data will be performed using Matlab (The Mathworks, Natick, MA, USA). Both novices and experts will be compared to each other by comparing the procedure time, pathlength (of the Aurora) and the sternum sensor of the Xsens will be compared between novice and expert. An average score of experts will be compared to an average score of the novices by means of a boxplot. To look at an average of the upper body movement, the sternum sensor was chosen, since this sensor is the closest one to the gravity center of the body.

A distinction will be made between four different phases for the analysis: mouth to z-line, z-line to retroflexion, retroflexion to pylorus in sight and intubation of the duodenum. For each phase the left hand movement and the torque movement of the scope are compared between an expert and a novice. In the left hand movement figures, seen from the endoscopist point of view, the X-direction is from left to right, the Y-direction is forward to backward movement and the Z-direction is up/down movement.

Out of the six experts, three were chosen to make an average of their left hand movement. Since movement of Asian experts is very different compared to European experts, only the European experts were chosen for the average[13]. For each expert the Xsens data was split into the four different phases as explained above. The three movements are divided into X-direction, Y-direction and Z-direction. For every direction the values of the three experts are added and divided by three to get to an average value. The calculation is shown in formulas 3, 4 and 5, in which X_1 is expert one, X_2 expert two and X_3 expert three, all in the X-direction. The same for formulas 4 and 5, but in Y or Z-direction. Average values are plotted for each phase in one figure, namely Figures 25 to 28.

$$AverageX - direction = \frac{X_1 + X_2 + X_3}{3} \tag{8}$$

$$AverageY - direction = \frac{Y_1 + Y_2 + Y_3}{3} \tag{9}$$

$$AverageZ - direction = \frac{Z_1 + Z_2 + Z_3}{3} \tag{10}$$

3.3 Results

In the following Figures 14, 15 and 16 the procedure time, pathlength of the Aurora and smoothness of sternum movement between novices and experts are compared. The experts are 21,1 seconds faster in performing the gastroscopy compared to the novices. The pathlength is 1,29 meter shorter than the novices and the movement of the sternum is 1,69 meter smaller than those performed by a novice.

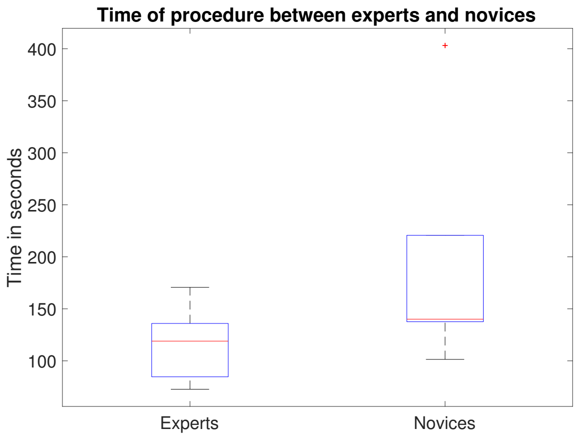

Figure 14: Average time per gastroscopy experts vs novices

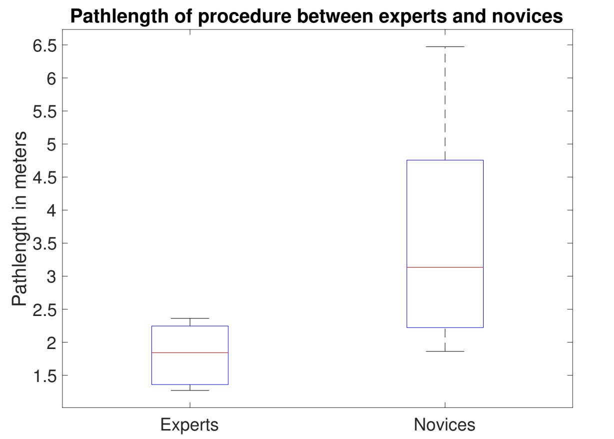

Figure 15: Average pathlength per gastroscopy experts vs novices

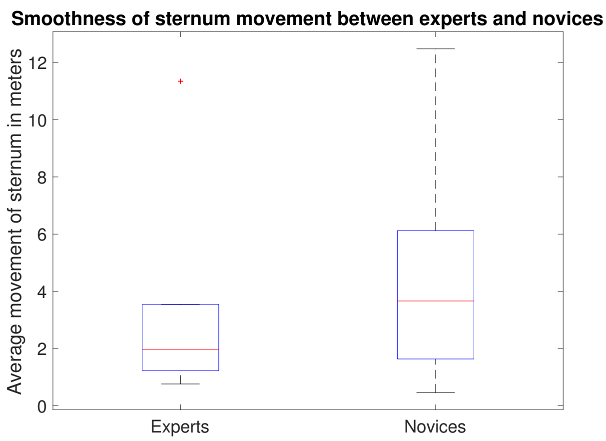

Figure 16: Smoothness per gastroscopy experts vs novices

The different movements of the left hand have been compared between an expert and a novice for the different phases, as well as the torque movement of the endoscope. This has been visualized in Figures 17 to 24. In the left hand movement figures, the X, Y and Z coordinates are plotted, while in the torque figures the rotation in degrees is plotted against time in seconds.

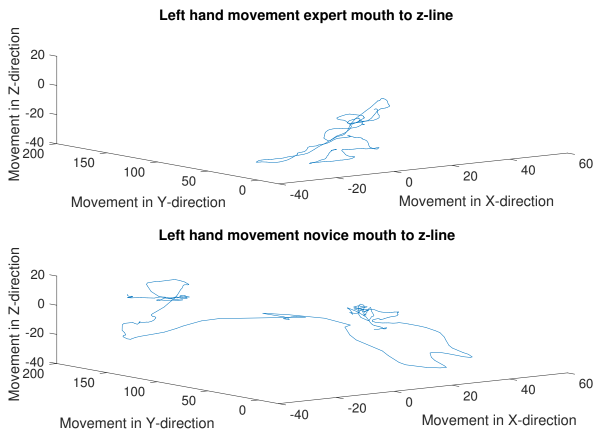

Figure 17: Left hand movement expert versus novice from mouth to z-line

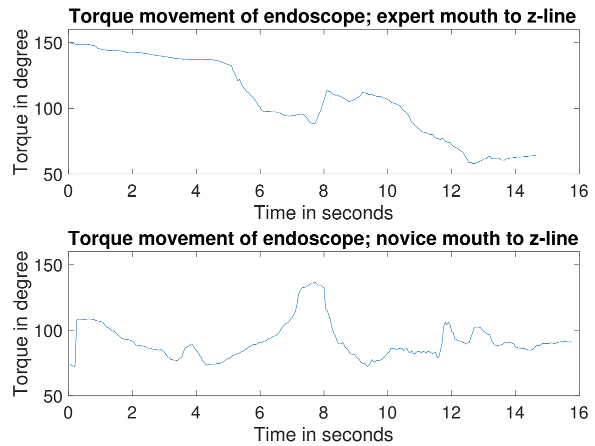

Figure 18: Torque movement expert versus novice from mouth to z-line

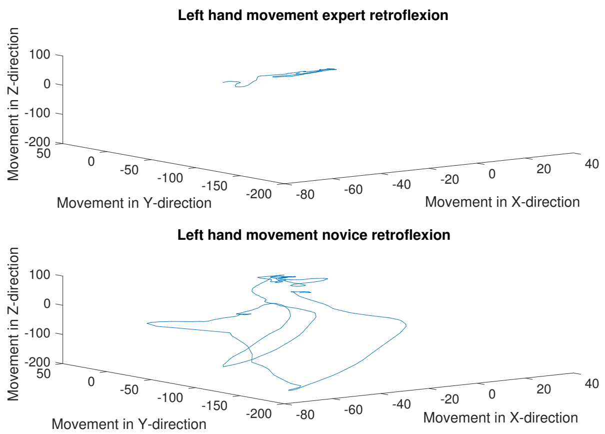

Figure 19: Left hand movement expert versus novice from z-line to retroflexion

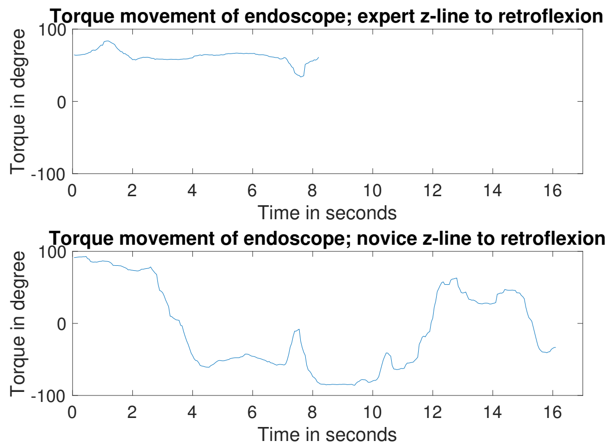

Figure 20: Torque movement expert versus novice from z-line to retroflexion

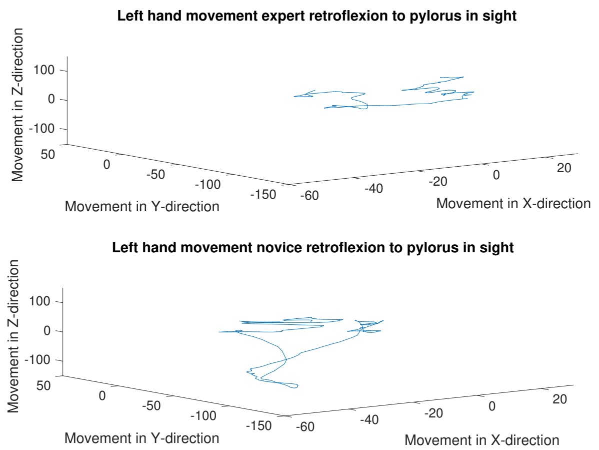

Figure 21: Left hand movement expert versus novice from retroflexion to pylorus

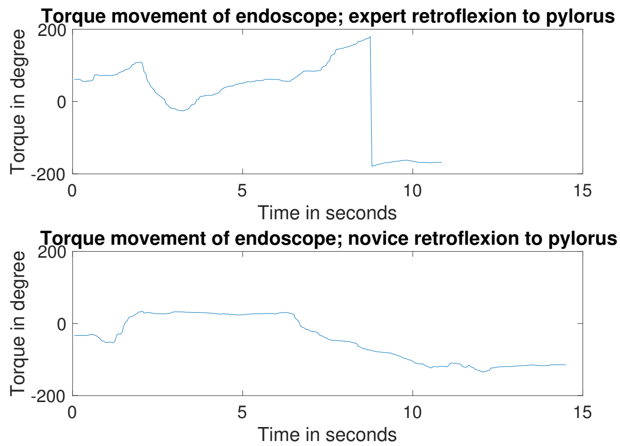

Figure 22: Torque movement expert versus novice from retroflexion to pylorus

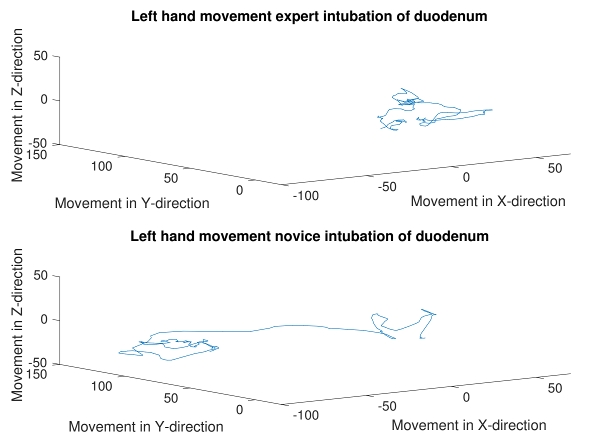

Figure 23: Left hand movement expert versus novice intubation of duodenum

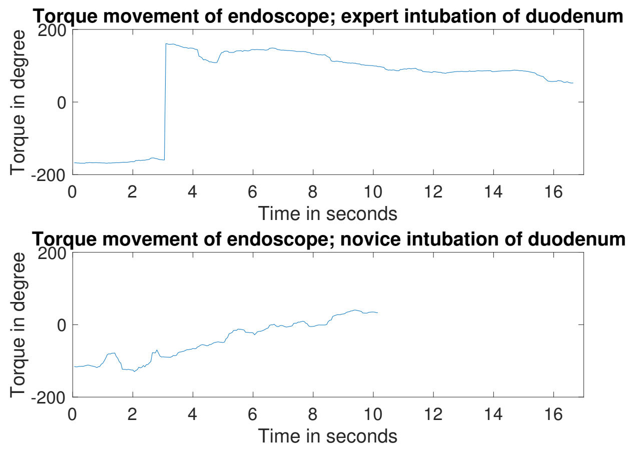

Figure 24: Torque movement expert versus novice intubation of duodenum

In the Figures 17, 19, 21 and 23 the novices move their left hand more in every direction than the experts. The expert have a smaller swing of their left hand. The torque movement of the expert is more gradually compare to the novice. During retroflexion the novice uses a lot of torque, while the expert uses almost no torque.

For three experts an average value is calculated and plotted into one figure. The black line represents the average movement. The measurement of the Xsens data does not start at the origin, by adding or subtracting the first value (x, y or z) from its entire corresponding column, the data will start at the origin. Afterwards the average movement matrix was calculated. An overview of the time for each phase between the experts is shown in Figure 29.

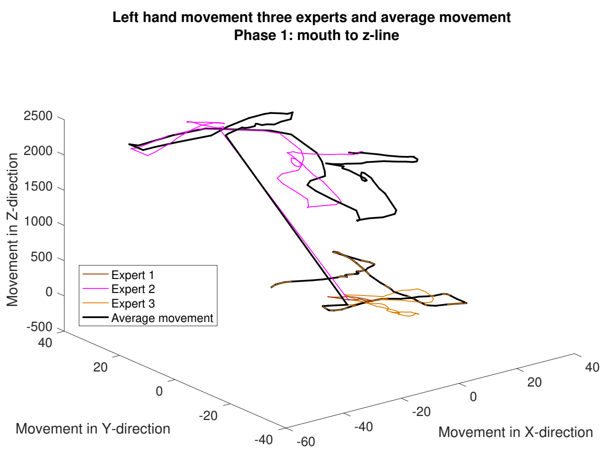

Figure 25: Average movement of left hand plotted for phase 1

Figure 26: Average movement of left hand plotted for phase 2

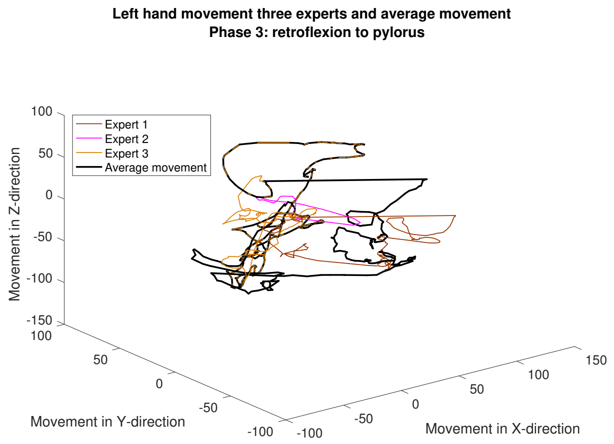

Figure 27: Average movement of left hand plotted for phase 3

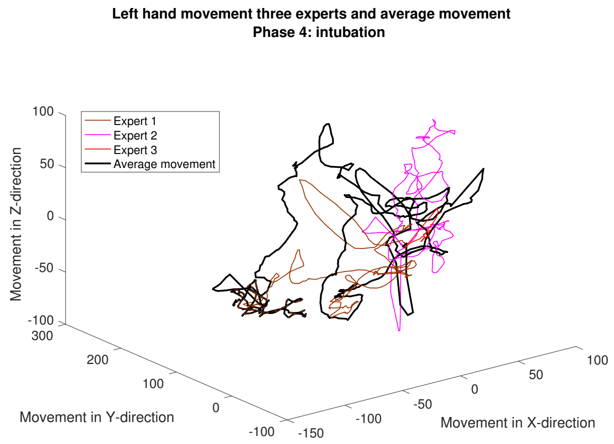

Figure 28: Average movement of left hand plotted for phase 4

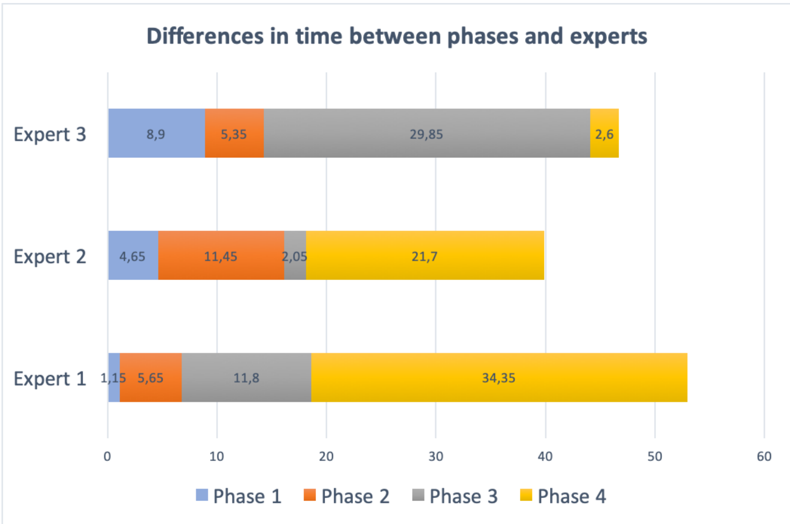

Figure 29: Time for every phase between experts

3.4 Discussion

The Figures 18, 20, 22 and 24 show that the novice uses a lot more rapid torque of the endoscope compared to the gradually changing torque angle the expert shows. In the Figures 22 and 24, it looks like the expert uses a lot of torque, however this is exactly 360 degrees and it depends on where the sensor starts measuring. The torque movement of the endoscope itself is not as large as it might look in the figure. The torque movement has been measured from +180 to -180 degrees, if the torque angle is +190 degrees, it will be shown as -170 degrees.

Nowadays novices learn endoscopy by observing and performing the procedure under supervision of an expert. When novices 'practice' on their first patients, they are more likely to encounter complications, patient discomfort and a prolonged procedure time.[12,27,28,29,30] Novices use their left hand more compared to experts. Because of the more extreme movement of their left hand and the torque, it would be beneficial for novices to train in a simulated environment first[6]. Especially now that experts have an increasing workload and less time to train the novice[31]. Experts are faster, have smoother movement of the upper body and has a shorter pathlength during a gastroscopy. This is to be expected since the experts have much more experience with endoscopy than the novices have. Previous studies have also shown that novices have a prolonged procedure time compared to experts[2,30].

The silicone stomach used for this pre-clinical trial was larger than a normal human stomach, and the pylorus was harder to intubate compared to a human stomach, according to most of the experts. This could end in a larger pathlength and increase of time to perform the gastroscopy. This could also be extra difficult for the novices, which would even more increase the time for the gastroscopy.

The average movement of the left hand was calculated for three experts. The data has been separated into the four previously indicated phases. However, the experts have a different duration of the phases. The average is based on the duration of the slowest expert. As long as their is data from three experts, there is an average movement, but if one expert takes longer to execute the phase and thus has more data, the average will only consist of one expert. In Figures 25 and 26 the average movement line is following expert 2 perfectly. Which means expert 2 took more time to perform the phase.

3.5 Conclusion

In conclusion experts show less movement of their left hand in every direction, and use torque of the endoscope gradually compared to novices, who use more torque (in both directions) of the endoscope. The data shows that experts use their body in a smoother way, which could result in less patient discomfort. This chapter has shown that there is a need for a teaching method on how to move the upper body and/or left hand for novices, and the serious game could be a way of teaching these novices how to move in an enjoyable way.

4 Clinical trial

4.1 Introduction

Since silicone or porcine models are different from human stomachs, the movement will also be measured within patients to back up our movement model in the serious game. The aim of the clinical trial is to get a database with movements of the Aurora (endoscope) and Xsens (endoscopist), which in turn can be used for validation of the serious game. The clinical trial is also executed to compare movements of the endoscopist in the three different models (human, silicone and pig).

4.2 Methods

The same recognition points used in the pre-clinical trial will be used during the clinical trial (Figure 12). The gastroscopy will be executed three times in a row, after starting the procedure for which the patient was indicated. The main difference between the pre-clinical and clinical trial is that between the measurements, the endoscope will not be removed from the esophagus. The measurements start from a little bit above the z-line. This decision was made since it is less harmful for patients.

Analysis will be performed using Matlab. Since the measurements started from the z-line, three phases will be distinguished during the analysis: z-line to retroflexion, retroflexion to pylorus and intubation of the duodenum. For each phase the left hand movement of the expert will be compared between the models and the in-vivo stomach. The data of the silicone model, the porcine model and the patient will be compared to each other for the same expert.

For the clinical trial a setup checklist will be written. Due to the stressful environment in the OR, it can be useful to have a checklist to make sure the setup is correctly followed. The checklist can be viewed in Appendix A.

4.3 Results

The silicone, porcine and human stomach for the same expert were compared. For comparison the left hand movement is chosen, since this movement will result in direct response of the endoscope and is considered the most important sensor in the analysis.

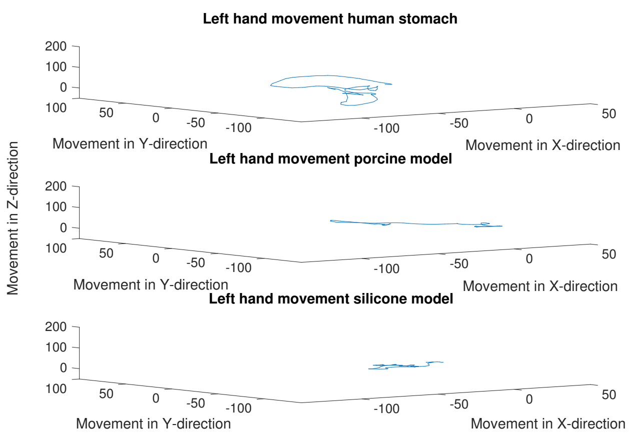

Figure 30: Average movement of left hand plotted for phase 1: z-line to retroflexion

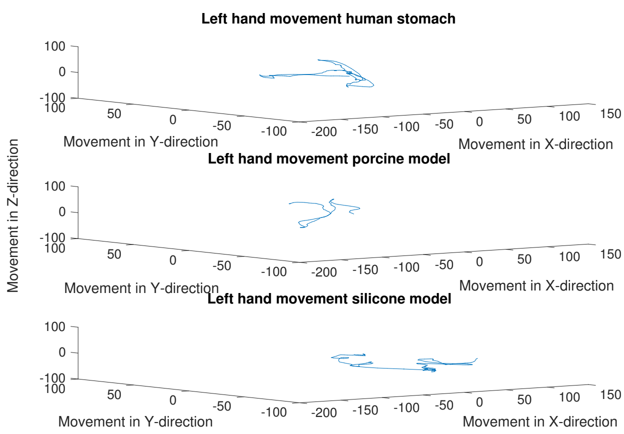

Figure 31: Average movement of left hand plotted for phase 2: retroflexion to pylorus

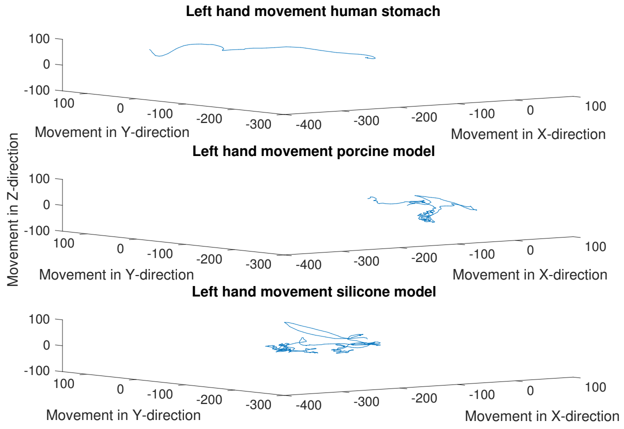

Figure 32: Average movement of left hand plotted for phase 3: intubation of the duodenum

The time to execute the different phases per model is shown in Figure 33.

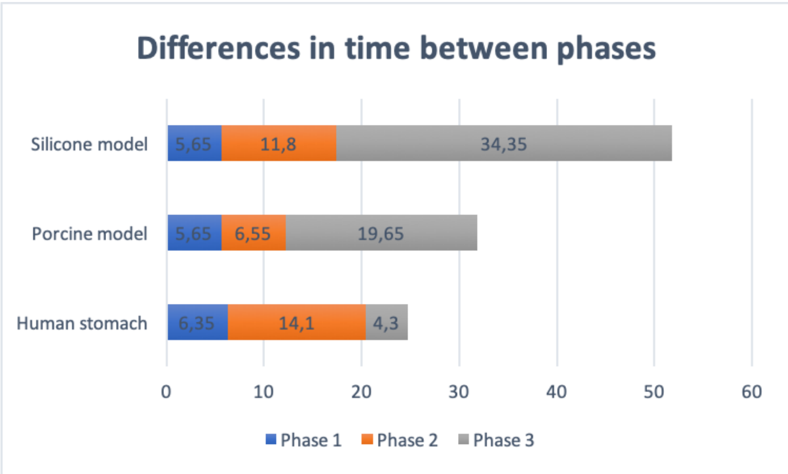

Figure 33: Time for every phase in the different models

4.4 Discussion

The expert has different left hand movements when performing the gastroscopy in the human stomach compared to either model. In Figure 30, left hand movements in the human stomach are more back and forth compared to both models, this could be due to the diaphragm present in the human body, in both models the esophagus is completely free from any other structure. During the intubation phase in the clinical trial there is one smooth movement from left to right and more towards the body. In the porcine and silicone model the movement is less smooth and the expert moves his hand back and forth, as shown in Figure 32. This could be due to the fact that in the human body the pylorus and duodenum are fixed. In both the models the stomach is held, but not fixed as firmly as in the body. If you push into the duodenum, the model might move within the mannequin. This could make intubation of the pylorus easier compared to both models. This could also be the reason for the prolonged time needed in both models. Particularly the silicone model intubation takes a long time, as confirmed by the expert himself.

During the clinical trial there was only one measurement available with the expert used for this chapter, due to unavailability of the experts or patients refusing to comply with the clinical trial. During the measurement, the patient was too close to the field generator, which made it impossible to measure any Aurora data. The only data available from this measurement was the Xsens data, hence comparison between pre-clinical and clinical, was performed only using body measurements. During later measurements of the patients, calibration of the Aurora system was impossible, which could make the data less accurate. Without calibration the measurements can still be executed, but re-sampling afterwards cannot be done. Before analysis, the data will be re-sampled, which will make the data become unusable.

4.5 Conclusion

To make the serious game more realistic, the clinical trial data is of importance, since the movement of the left hand of the endoscopist is different in a human stomach compared to the porcine or silicone model. However, more data has to be collected to prove this data to be of significant difference.

5 Implementation in serious game

5.1 Introduction

The collected data will be used to validate movements of the virtual endoscope in the physics-based simulation. Afterwards, the simulation will be used as an input for the serious game. The objective of the serious game is to train future endoscopists to correctly manipulate and use an endoscope during medical procedures in a novel way.

5.2 Methods

The serious game should be low-cost and easily accessible for all trainees. In order to achieve this, two main parts had to be developed:
Firstly, a hardware part, which is an exact replica of a real endoscope (both handle and schaft). The physical model had to be modeled and 3D printed. It also had to integrate electronics in order to measure its orientation in space, the movement of both wheels, and button actuation. The data will be received locally by an Arduino board, which will then send it to the computer hosting the simulation/game. Both hardware parts are connected to the computer via USB cables.
Secondly, a software part reproducing the simulated shape of an endoscope. This virtual endoscope is modeled in a 3D physics-based simulation called Simulation Open Framework Architecture (SOFA). A succession of beams (based on timoshenko beam theory) is used to describe the behaviour of the shaft over time. The virtual endoscope is driven in the simulation by the data acquired from the hardware parts. The data received from both the Arduino board and the shaft sensor will be used to control the shaft of the virtual endoscope. Turning of the wheels will result in a movement of the tip in the simulation/game.

A new 3D print of the physical endoscope will be made that is more realistic. The old endoscope model is shown in Figure 34 and the new endoscope model is shown in Figure 35. Inside the printed endoscope there is a double potentiometer for both the wheels (one for each), five buttons (actuators), an Arduino mini and the BN055 from Adafruit. The potentiometer can give information about how much it has turned in a certain direction, which can be linked to the turning of the wheels. The Arduino mini is the 'computer' of the endoscope, it is the board that makes connection with a real computer and the one that can receive and transmit information. All the sensors are connected to this board, which will transmit the information to the computer. Using the Arduino IDE, the Arduino can be programmed to read and process sensor data and pass it to the serious game via serial communication. The BN055 is a 9DOF sensor, which has a 3-axis acceleration, 3-axis gyroscope and a 3-axis magnetometer.

Figure 34: Old model 3D printed endoscope

Figure 35: Updated 3D printed endoscope

The simulation reproducing the virtual endoscope had to be validated in order to assess the described behaviour compared to the real physical endoscope, and that the virtual endoscope will be correctly driven by the hardware input. An early strategy used to evaluate the simulated hardware involved the generation of arbitrary Xsens data. This synthetic data was fed to the SOFA-based system to imitate body movement while the physical endoscope controller was being manipulated. After some promising results, it was decided that the actual physical endoscope and shaft sensor will be used to drive the simulation/the serious game. The Xsens data gave both the position and orientation of the handle at the position of its left hand, while the physical endoscope is only able to give the orientation of the handle, using the BN055 IMU sensor. For this reason the camera CAD model was modified to fit a BN055 on a real endoscope. The BN055 IMU sensor is connected to an Arduino mini so sensor data can be transmitted to the computer. In a pre-clinical setting the measurements were recorded once more to record the measurements of the BN055 IMU sensor with the Aurora probe, to directly use this data for the serious game.

For the game both Unity (Unity Technologies) and Simulation Open Framework Architecture (SOFA) will be used for programming. SOFA has been developed by Institut national de recherche en informatique et en automatique (Inria, France) and works with C++ and XML code. Unity has been developed especially for computer games and works with C# or UnityScript (a Javascript derivative).

In SOFA the movement of the endoscope and endoscopist will be reconstructed into a simulation, used to aid the novice by "replaying" the experts movements virtually. All recorded points of the Xsens and Aurora tracking technologies are read from text files and inserted in the SOFA simulation in specific components called 'MechanicalObjects'. As the time signature of the experts' movements was recorded, these movements can be virtually replicated at the same speed. The same way it will be in the final simulation/game with the developed hardware it is possible to drive the virtual endoscope at the same strategic positions with these Aurora and Xsens data, as well as with the Aurora data and the dedicated BN055 IMU sensor.

Unity will be used to develop a simulated and more realistic game environment. In the game a character in a labyrinth will be simulated. The shaft sensor which measures if the physical endoscope is pushed forward or pulled backwards is used to make the person walk forward or backward. The shaft sensor is shown in Figure 36. The BN055 IMU sensor in the physical endoscope handle measures rotation of the handle and this rotation is correlated to the turning of the character, allowing the player to turn the body left or right. The wheels of the endoscope turn the characters head, allowing to look left or right. A screenshot of the game is shown in Figure 37. You can see the character moving in the main screen and to simulate the endoscope the view of the character is shown in the small screen in the right lower corner.

Figure 36: 3D printed 'insertion point' with infrared sensor and fake scope

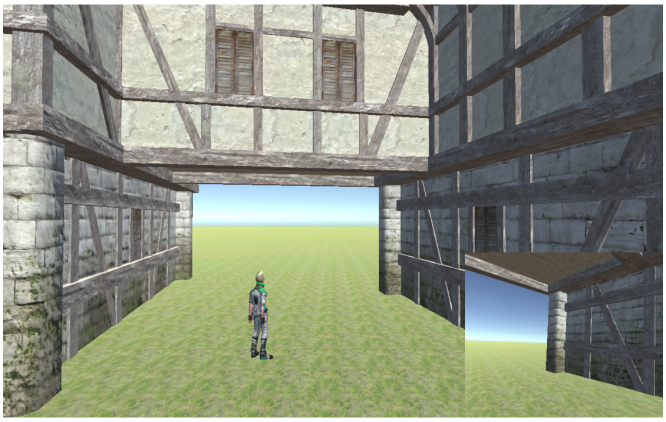

Figure 37: Screenshot of the Unity game

5.3 Results

The recorded data was reconstructed in SOFA. The data from the Xsens suit and the Aurora probes can be used to drive the virtual endoscope modeled in the simulated environment. The behaviour of the virtual endoscope is based on beam theory, adapted for this specific case (under gravity) by tuning physical parameters such as geometry, mass or stiffness. A screenshot from this simulation is shown in Figures 38 and 39. In those Figures the orientation of certain sensors are given. Both hands (from the Xsens data) have an orientation. By displaying them it is possible to understand how the hands are rotated. The X, Y and Z axis are displayed by red, green and blue colors. A simulated insertion point is defined from the Aurora data (located at the tip of the endoscope in Figure 38). The virtual endoscope (displayed with smaller frames making it mostly green in the screenshots) is driven using the pose of the left hand and the location of this insertion point. Figure 39 shows the same simulation after 10 seconds, the insertion point is now close to the right hand. During the measurements, the real endoscope was inserted into the shaft sensor, as shown in Figure 36 and the endoscopist moved the wheels and the handle in 3D space in order to acquire how a real endoscope is behaving. In Figure 39 the measured real endoscope is also displayed with big frames (one for each Aurora sensor). Having both real (measured) and virtual (simulated) endoscopes in the same simulation makes comparisons in shape and behaviour possible.

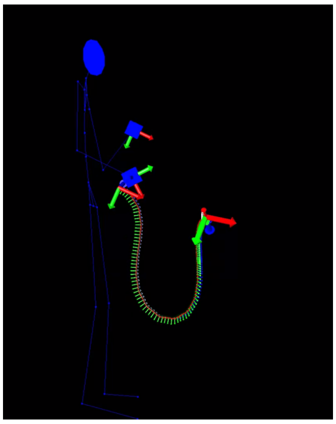

Figure 38: Reconstruction of Xsens and Aurora data

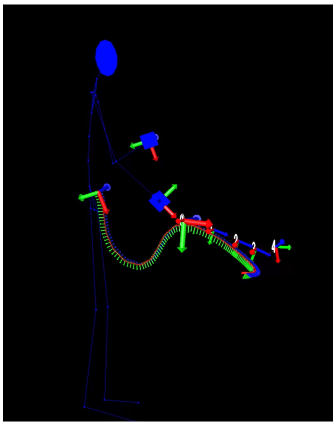

Figure 39: Reconstruction of Xsens and Aurora data

If the scope is pushed forward through the shaft sensor, the scope will also move forward in the simulation. Turning the wheels will result in turning of the tip of the simulated endoscope. By rotating the scope handle, the orientation of the simulated scope will change to simulate torque movement.

5.4 Discussion

All the recorded data can be implemented in SOFA to validate the virtual endoscope model. While it was interesting to observe that the virtual endoscope is approximately behaving the same way a real endoscope does, it is still unclear exactly how to use the recorded Xsens data in the game. Previous work has shown that multiple ways of moving the endoscope can result in the same small motion needed to achieve specific medical tasks[13]. The Xsens suit and the Aurora tracking system allow recordings of movements of both the endoscope and the endoscopist, while the developed physical endoscope provides less information (eg. only the orientation of the handle, not its 3D position).

Simulations and serious games allow novices to practice until they reached a predefined learning outcome[17,32]. In a serious game complications or difficult situations can be simulated for the novice to learn how to deal with these situations in a safe environment. Serious games provide a high level of interactivity that cannot be easily achieved in a real life training situation. The skills learned during a serious game can be transferred to a real life situation[32], but it is important that the skills are thought in a correct manner[17]. Echnochsson et al. have found a positive correlation between students who played computer games and their performance in endoscopic simulations due to their three-dimensional perception experience from these games[33].

The game technology allows for a low-cost simulator, which is both engaging and accurate, when compared to traditional simulators[17]. The main advantage of a serious game over a traditional simulator is the ability to invoke voluntary play by a competition element or attractive game play[9,31,34]. Furthermore, validated serious games potentially shorten the learning curve of novices[2].

5.5 Conclusion

The serious game is a good first step in learning that movement of the left hand has an influence on the endoscope. However, the Xsens incorporates too many body segments to be implemented in the game in the same manner. The 3D printed endoscope handle has only one sensor, whereas the Xsens possesses

17. A way has to be found to implement the Xsens data from all sensors into the serious game, showing informational simulations could be a solution for this.

6 General conclusion

The goal of this study was to develop a new way to teach novices endoscopic skills by means of a serious game. The game will give feedback on psychomotor skills during flexible endoscopic maneuvers. To evaluate if this goal is met, the research questions will be answered in this chapter.

Which movements are relevant during a standard diagnostic gastroscopy and can they be reproduced in the serious game?
In the serious game there will only be a sensor in the physical endoscope handle. Therefore, the focus of this study was on movement of the left hand of the endoscopist. Left hand movement shows a correlated movement in the endoscope shaft. Specifically, the key component of left hand movement is the translational movement from left to right, for example seen during the intubation of the duodenum.

How does upper body movement differ when performing gastroscopy on silicone stomachs, pig stomach models or human stomachs?
When performing a diagnostic gastroscopy, there are differences between the models and the in-vivo gastroscopy. In humans, the z-line to retroflexion phase, shows more forward/backward movements of the left hand compared to the same phase in either model. In phase 3, intubation of the duodenum, there is a more smooth left/right motion of the left hand in the human stomach. The pylorus and duodenum are embedded in the body and therefore less capable of moving when the endoscope pushes to intubate. In both models the stomach lays relatively loosely in the mannequin. When the endoscope pushes to get into the duodenum, the model will move. This makes it harder to intubate the duodenum and influences the data.

Is it possible to synthesize an ideal expert from the expert database?
There are cultural differences between how the endoscope is manipulated. The Asian endoscopists hold the endoscope more horizontally compared to European endoscopists. It is unclear whether either method is more successful than the other. European experts were chosen for this work because of the institute's geographical location and associated access to study participants. The three European experts were simply averaged one-for-one. This method has inherent limitations, such as the inability to compensate for movement recordings of different lengths. Future work should involve finding a better way to consolidate the experts' movement libraries. Furthermore, control inputs on the endoscope handle can have an ambiguous relationship with the resulting movement of the endoscope shaft, thereby adding further complexity to this problem.

The above questions are used to investigate the main research question, which is:
How can upper body movement measurements be used for psychomotor skill instruction in a serious game?
Since the serious game will only measure the movement of the physical endoscope handle, it is important to look at the left hand sensor. The other sensors of the Xsens are used for simulation in the serious game, but more research has to be performed on how to implement all the data from every sensor in the game itself. For a simulation the measurements with the Xsens in a clinical trial are of importance. However, for the serious game, the movement of the endoscope handle relative to the endoscope shaft is important. No clinical trial measurement is needed for the implementation of the game.

7 Future recommendations

In the pre-clinical trial a silicone stomach model has been used. However, the model is different from a normal human stomach. The stomach was larger and had some abnormalities, such as polyps. Experts explained the stomach was more difficult to perform a gastroscopy on compared to a patient, with the duodenum being especially hard to intubate. It is possible that experts had to make upper body movements for intubation they would not normally do. A solution could be to perform a clinical trial or a gastroscopy on ex-vivo stomachs or perform the gastroscopy on pigs. That said, the experts also had problems with intubation of the pig stomach model due to the loose attachment of the stomach in the mannequin.

Several issues presented themselves during the clinical trial. The first of which was the fixed position of the patient bed. After calibration of the Aurora field generator, the bed cannot be moved in any direction. The calibration of the system takes about ten minutes, but most often there was no time for calibration or the patient had already been rolled into the operating room. For the calibration to work, the patient cannot already be in the bed, meaning the patient needs to walk to the operating room. It is recommended that the ground be marked with tape, so that the bed will be placed in the same position. This could result in slightly lower accuracy, but removes an organisational barrier to performing the study, and is more comfortable for the patients. The calibration itself is used to give the Aurora and the Xsens the same timestamp after the experiment, but the original Aurora and Xsens data are also recorded. This data from this systems is not time stamped unless the in-house recording software is used. Meaning, that it is impossible to link the movement of the endoscope to the endoscopist if the calibration is not performed.

The Aurora probe used during the experiments (both clinical and pre-clinical) is very fragile. If it is inserted into the working channel it will kink easily. Once it has been bent too much, it becomes impossible to insert it into the working channel. The force used to insert the probe in the working channel is greater than the force required to kink it, so it will always bend. So great care must be taken when inserting the probe. A way to strengthen the probe has to be found if experiments are to be continued. The portion of the probe shaft that remains outside the endoscope channel on the proximal end was wrapped with heat shrink tubing to reinforce it. However, even the thin layer of heat shrink makes the diameter of the probe too large to fit into the working channel.

The kinect camera films the endoscopist performing the procedure, but is also necessary for the head tracking of the endoscopist, to later overlap the Xsens data with the actual video. In the OR there are multiple persons (anesthesiologist, nurse, possible observers), who are often in the video. The kinect has a field of view of 70.6°, which is why the other staff will be in the image[35]. A way to prevent this is to tell everyone to be behind the camera. This can only be possible if it is a safe situation for the patient.

For the serious game only the BN055 IMU sensor is used in the physical endoscope. To easily input this data into the game, it could be useful to also attach this sensor to the real endoscope during the clinical trial. However, this does mean one more sensor on the endoscope and one more cable that needs to be connected to the computer. With the camera on the endoscope as well, this sensor can be perceived as annoying and cumbersome. Additionally, the sensor should be located as closely to the left hand as possible, thereby interfering with the hand operating the endoscope.

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A Clinical trial setup

Checklist setup Endomove

Figure 1: Camera next to Olympus screen

- ☐ Place the computer on a cart and put it behind the Olympus column.
- ☐ Charge the computer
- ☐ Place the Kinect camera next to the Olympus column, as shown in Figure 1.
- ☐ Connect the Kinect to the camera to the computer → directly in USB computer
- ☐ Make sure the Kinect can see the patient bed and endoscopist. This can be checked by starting the camera application on the computer.
- ☐ Place the NDI recorder box underneath the computer.
- ☐ Connect the NDI recorder box to the computer and plug it in the wall socket
- ☐ Connect the Olympus image to the computer directly. The connection for the Olympus is on the backside of the screen. See Figure 2. It is on DVI1 Out.

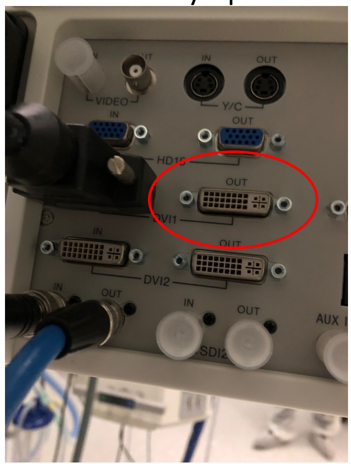


Figure 2: Connection to Olympus

- ☐ Roll the patient bed in the room. Place the aurora underneath the mattress. To gain the right height for the tracker. Get two mattresses.
- ☐ Connect the aurora board to the NDI recorder box.
- ☐ Launch the Everest recorder. Click on management and turn on the Kinect camera (by clicking on Kinect 2).
- ☐ Connect the 6DOF probe from the checkerboard to the NDI at position 1 → see Figure 3
- ☐ Click on Registration and click on Aurora / Video registration. A new screen appears. Select the infra-red camera from Kinect and select checkerboard I.

Figure 3: Connection to Aurora box

- ☐ Connect the footpath to the computer
- ☐ Use the checkerboard above the aurora generator and use the left pedal on the footpath to capture the image. Capture around 20 images for calibration.
- ☐ Run the optimalization to see which one is best. Open the text file to see the lowest x value. Run optimalization again with only that one checked.
- ☐ IMPORTANT: DON'T MOVE THE BED ANYMORE
- ☐ → Patient can now walk into the room

- ☐ Place the color bands on the endoscope. Start between the U and D letters and have the letters on the color band at the handle site. As shown in figure 4.

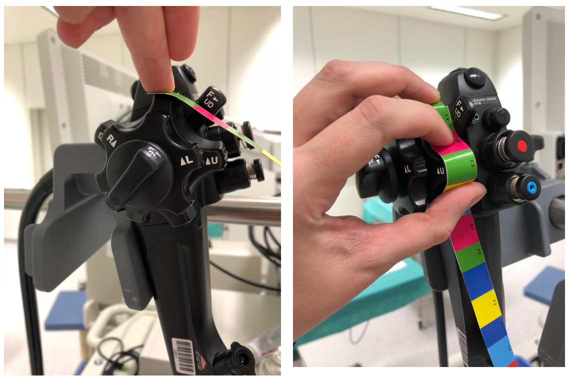


Figure 4: Color band

- ☐ Place the webcam on the endoscope handle. Use tape to attach it firmly
- ☐ Connect the webcam to the USB hub to have enough wire. Turn on the camera application and check if the webcam gives a clear image, otherwise put hand behind wheels.

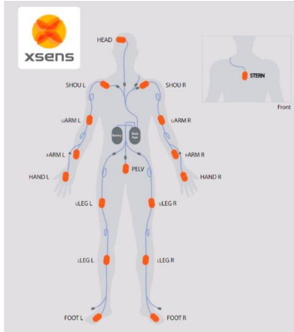


Figure 5: Placement of sensors

- ☐ Put on Xsens suit. See Figure 5 for where to place the sensors.
- ☐ Plug in Xsens receiver and launch the Xsens application → MVN Studio 4.97.1
- ☐ Close the first pop-up and select new file (top left).
- ☐ Check if all the sensors are on by pressing on the arrow to the right → see Figure 6

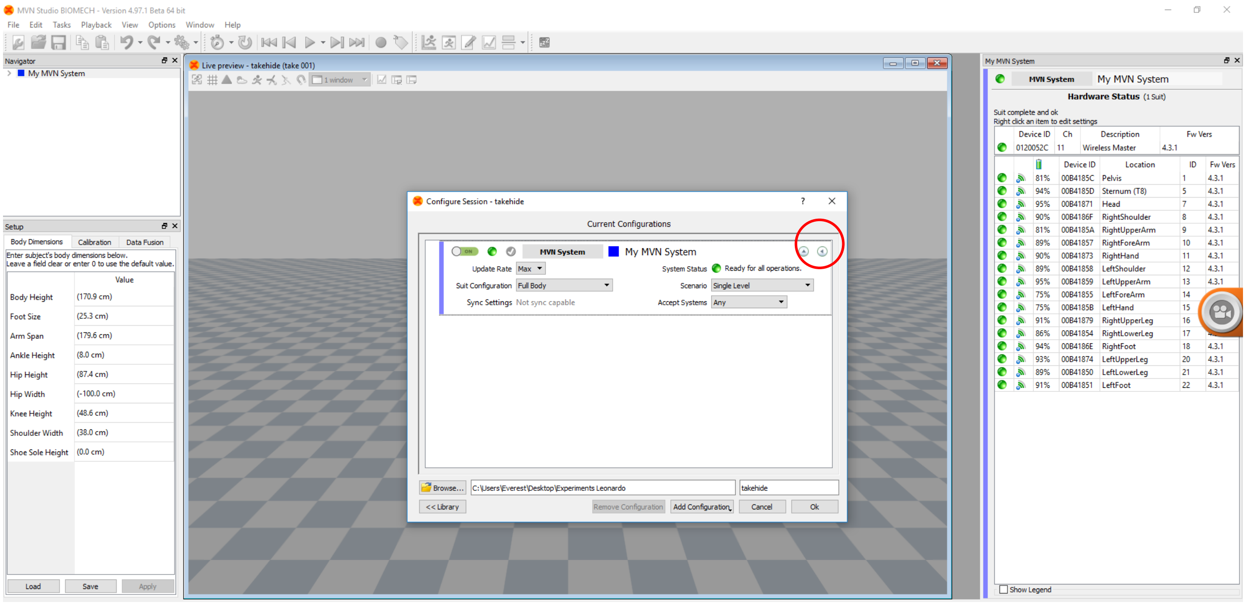


Figure 6: Xsens software

- ☐ All the sensors should be green
- ☐ Either measure the endoscopist or load in previous measurements.
- ☐ Select calibration and choose T-pose.
- ☐ Go back to Everest recorder, Xsens should now be green

<u>The endoscopist will do her/his own procedure first</u>

- ☐ Put the probe in the working channel. Be careful so it will not bent. The probe should barely be visible in the screen, but make sure it reaches the end of the endoscope.
- ☐ Use tape to attach the probe to the endoscope handle
- ☐ Connect probe to the box of aurora → See Figure 7
- ☐ Go to the Everest recorder and initialize the tracking system
- ☐ Before starting, make sure the light in the room is normal (no green or pink)
- ☐ Click on record. Two black screens will pop up, wait until you see writing happening on BOTH screens

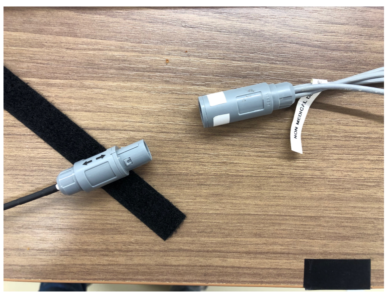


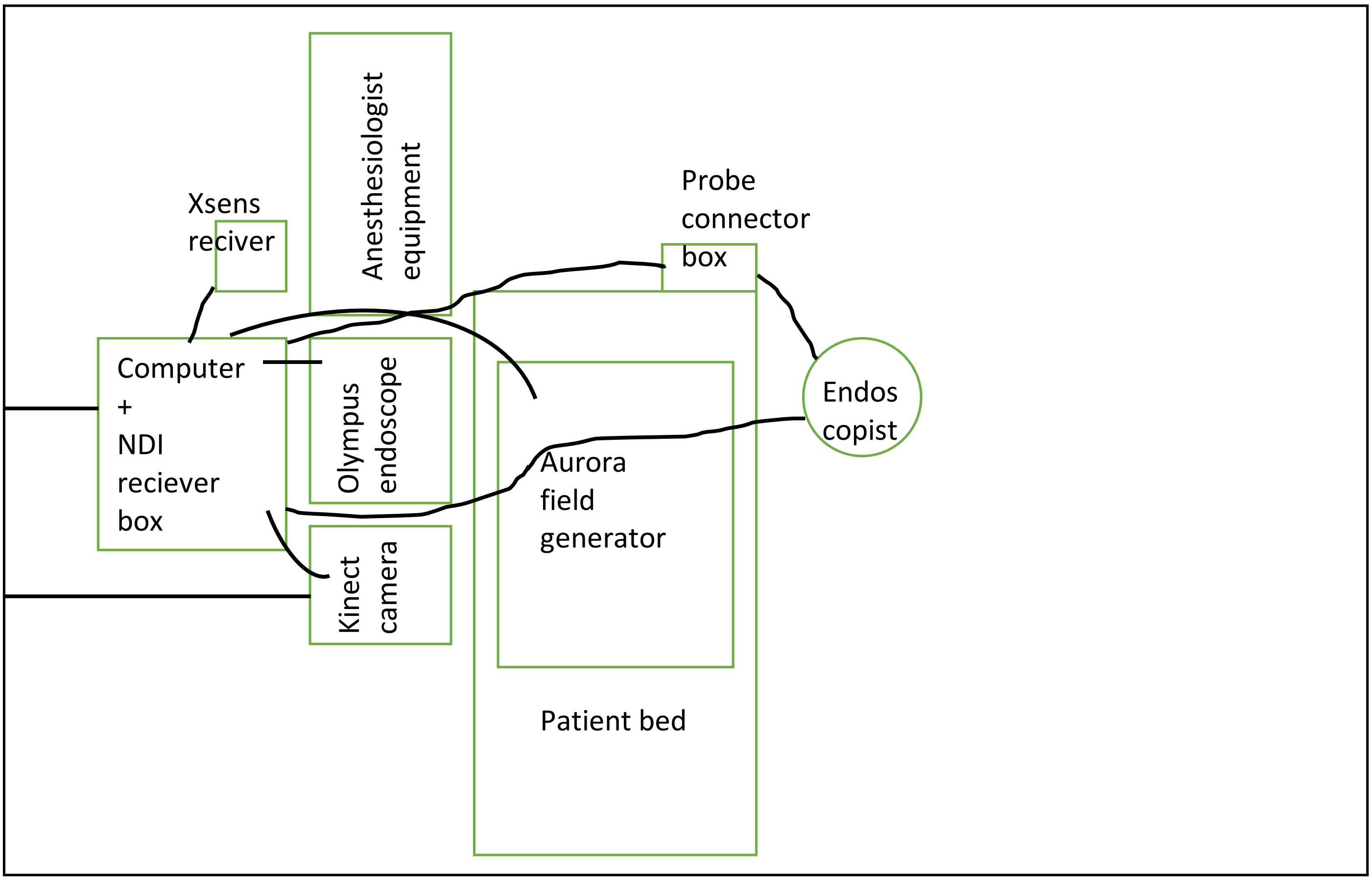
Figure 7: Connection to Aurora box

- ☐ Now you can start the measurements.
- ☐ Double click on the events when the endoscopist tells you where he/she is in the body
- ☐ After three times, click on stop to stop the recording

<u>Don't forget to disconnect the board before they roll out the patient! → See Figure 8</u>

- ☐ Bring the probe to sterilization and ask for cold sterilization (takes about 15 minutes)

Figure 8: Connection to magnetic field generator



In the Figure above, the Kinect camera is connected to the wall socket, and to the computer. The NDI receiver is connected to the wall socket, to the computer, the aurora field generator and to the probe connector box. The probe connector box is connected to the probe, which goes into the endoscope. The endoscope is also connected to the webcam, which is connected to the computer. The computer is connected to the Kinect, Olympus image, Webcam on endoscope, NDI receiver box and Xsens receiver.

B Endotraining

Flexible endoscopy is shifting from a diagnostic tool to an interventional one. Technically demanding interventional procedures are complex to teach. At the same time, the longstanding apprenticeship-based Halstedian model of teaching is being challenged by legal and ethical concerns for patient safety, working time restrictions, the cost of operating room (OR) time, and complications [36]. Teaching and assessment needs have to be addressed with properly designed curriculums off the OR. Virtual-reality (VR) flexible endoscopic simulators could serve this need, but there are often prohibitively expensive. On the other side, analogic low cost alternative could have a more widespread impact if properly designed and validated.

The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) has designed and validated the Fundamentals of Endoscopic Surgery (FES), a high-stakes exam validated to certify competency in flexible endoscopy [37]. FES consists of a didactic component and an examination. The former is provided with online materials and the latter is composed of a knowledge valuation and a hands-on skills test. Since at the time an inexpensive suitable platform wasn't identified, SAGES decided to validate its manual skills test using a virtual-reality simulator, the GI Mentor 2 (Simbionix Ltd, Airport City, Israel).

Starting in 2018, the American Board of Surgery (ABS) requires all candidates to be certified in FES to sit for their licensing examination. All residency programs are required to offer trainees the Flexible Endoscopy Curriculum (FEC), a mixture of didactic and practice recommendations. Current Accreditation Council for Graduate Medical Education (ACGME)/ABS requires that residents perform at least 85 endoscopic procedures (35 Upper Endoscopies and 50 Colonoscopies). This alone however, seems insufficient to pass the manual skills exams, as indicated by a 25% failure rate among general surgery residents [38]. In the same study, Gardner et al did show that performing 105 endoscopic procedures is a good predictor of FES success [38]. Similarly, Mueller et al found that a Global Assessment of Gastrointestinal Endoscopic Skills-Colonoscopy (GAGES-C) score over 15/20 seems to be predicting FES success [39]. Unfortunately many surgical training programs lack access to such high volumes of cases.

Virtual reality (VR) based simulation training has also been shown to increase FES performance compared to an endoscopic rotation alone [40]. However it is difficult to advocate for widespread use of VR training platforms given their high costs. The need for affordable simulation based training is being addressed by a number of groups. In 2013, Ritter et al. proposed the Simulated Colonoscopy Objective Performance Evaluation (SCOPE) using the Kyoto Kagaku colonoscopic model [41]. SCOPE was validated [42] on 4 simulated tasks: scope manipulation, tool targeting, loop management and mucosal inspection. The model, updated with the addition of a retroflexion task, and was renamed endoscopy training system (ETS) and further validated. The same group has recently reported important improvements on FES manual skills exam scores among surgical residents training on the ETS platform following a mastery learning strategy [43].

Recently, Crispin et al. have adapted the Fundamentals of Laparoscopic Surgery (FLS) training box to be used with a flexible endoscope [44]. The resulting model, named the Basic Endoscopic Skills Training (BEST) box, provides 6 modules: peg transfer forward-view, peg transfer in retroflexion, puncturing, snaring, clipping and cannulating. Each task can be performed in a maximum of 5 minutes. Scores are based on performance efficiency, incorporating time and number of potential errors. Preliminary results show how this analogic system is able to discriminate between expert and novices in flexible endoscopy, but up to now there is no evidence in literature about the use of BEST box for training of novices.

Novices (less then 10 endoscopic procedures performed) will be asked to sign a consent form and get a short introduction into flexible endoscopy by an expert. They will be explained how to use the wheels on the endoscope and how to move the body to move the endoscope shaft. On day one the participants will fill out a questionnaire about their interest and background. Then the participants will be randomly divided to test the in house developed BEST box or GI Mentor. The participants will practice flexible endoscopy for 10 days. On day 1, 5, and 10 they will perform the FES exam on the GI Mentor. On day 10 they will also perform an ex-vivo exam and end with an user-experience questionnaire. The overview of this method can be seen in Figure 40.

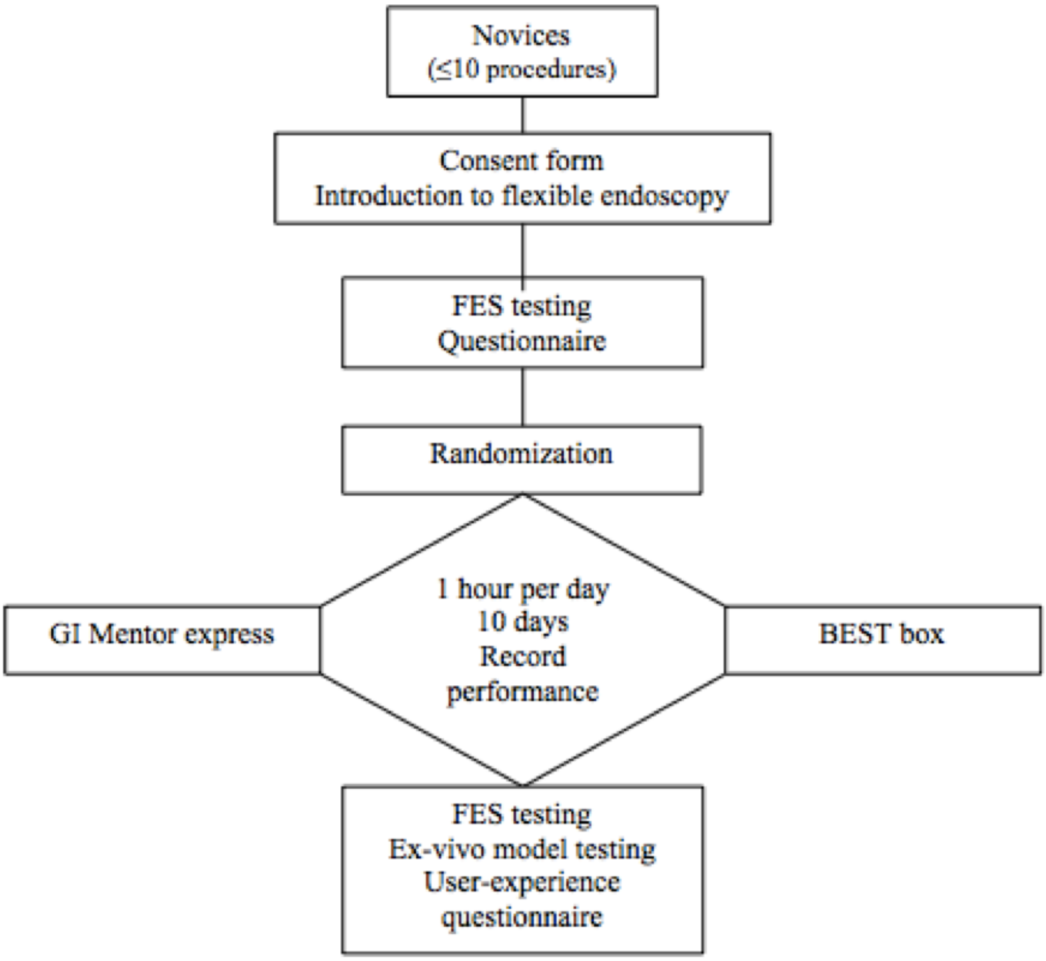


Figure 40: Method endotraining

C 2D, 3D and 4K laparoscopic movement

Since its introduction, laparoscopic surgery has shown clear advantages for patients in terms of post-operative pain, early mobilization and a faster return to normal daily activity. On the other hand, it has disrupted traditional surgical workflow. Two-dimensional (2D) laparoscopic vision systems result in less information for the surgeon because of the loss of stereotactic vision. However, experienced surgeons manage to estimate three-dimensional (3D) information from indirect visual cues such as motion shadows and anatomical benchmarks. Nevertheless, Way et al. analyzed 252 cases of laparoscopic bile duct injuries finding that 97% of events were caused by visual misperception[45]. To overcome these limitations, 3D laparoscopic technologies synthesizing images from a dual-channel 3D laparoscope have been introduced nearly three decades ago. A recent review of 31 RCTs comparing 2D and 3D visions in clinical situation and in simulated surgical tasks, showed an advantage of 3D both in terms of procedure time and technical errors in 71% and 63% of studies respectively [46]. Cognitive workload and vision-related side effects were heterogeneously reported and vary greatly depending on the utilized system. However, no definitive conclusions were drawn. As a matter of fact, 3D technologies are still not routinely used in most surgical practices. The constant improvement of technology in surgical vision limits the ability to compare results between 2D and 3D vision. Sakata et al. addressed the issue by stratifying 3D performances according to old and new 3D technologies [47]. The first generation of 3D technologies needed heavy active glasses; the second generation used head mounted displays; and the third generation uses passive polarizing glasses. In brief, older technologies offered poor resolutions and suboptimal 3D rendering compared to current solutions and standard 2D. Even though these limitations seem resolved nowadays, visual strains and side effects together with increased cognitive workload and the need for optimal screen positioning in respect to the operator still limit the widespread adoption of 3D in laparoscopic surgery [47]. 4K displays have only been recently introduced to increase image resolutions and spatial orientation during surgeries. Preliminary results in a simulate environment suggest that 3D and 4K displays speed up procedures and learning times in novices compared to 2D systems. Additionally, 4K could increase accuracy in advanced tasks [48].

In this study the 2D-to-3D system developed in IRCAD Taiwan will be compared to the 3D system, the HD and 4K system from Karl Storz. 60 novices executed the LASTT experiment on each of the systems (so 15 participants per system). 10 experts performed the LASTT experiment on each of the systems. The participants are asked to sign a consent form and will be shown explanatory videos about the tasks they will have to perform. Participants are randomized based on age and gender. They will execute the three tasks each three times. Afterwards they will fill out a post-questionnaire in which they are asked for visual strain, dizziness, nausea, headache, wrist, and shoulder pain. An overview of the method can be seen in Figure 41.

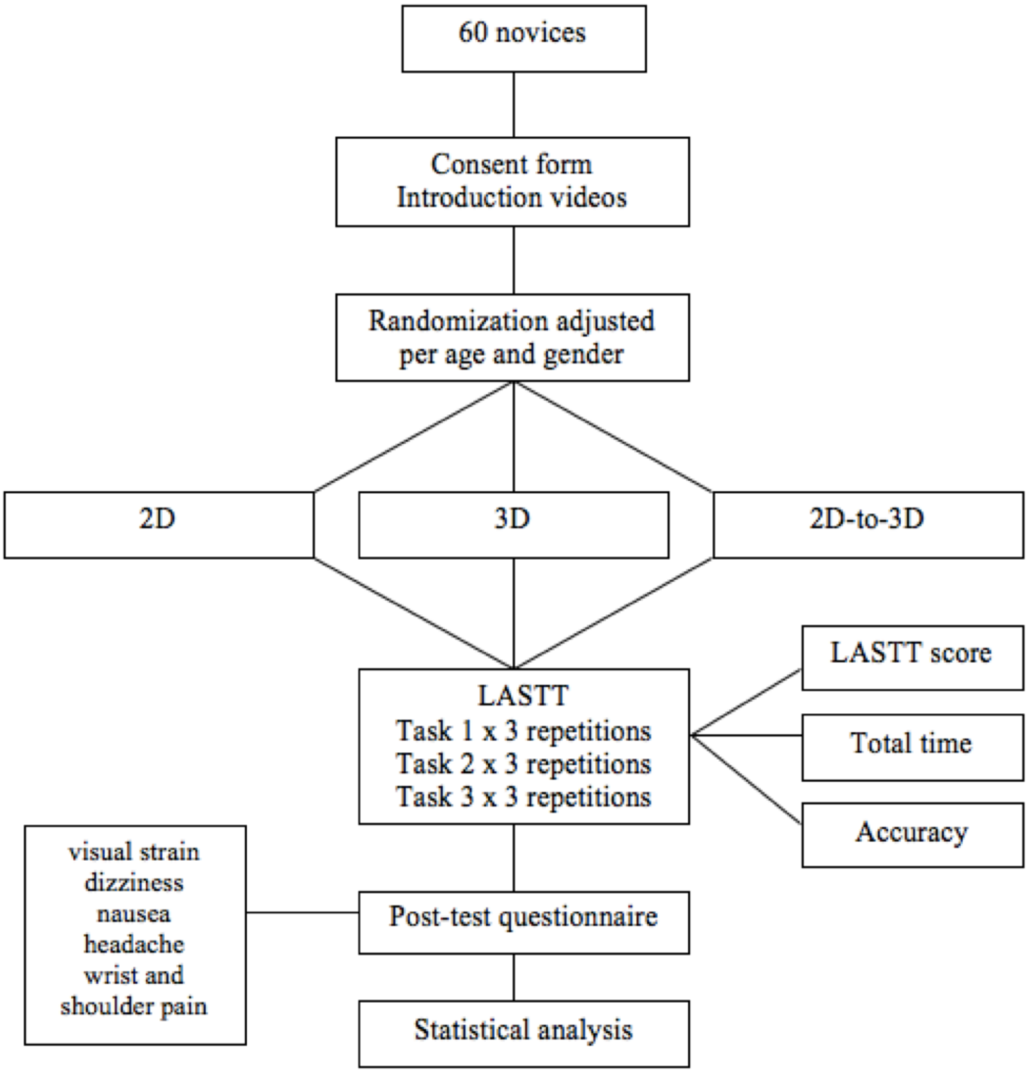


Figure 41: Method 2D, 3D and 2D-to-3D experiment