



CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING

Department of Biomedical Technology

**Sensing and Processing of the Image and Video from the
Colposcope During the Conization**

Bachelor Thesis

Study program: Biomedical and Clinical Engineering
Study branch: Biomedical Technician

Bachelor thesis supervisor: doc. Ing. Jiří Hozman, Ph.D

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Kladno 2021



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Sensing and processing of the image and video from colposcope during the conization

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Snímání a zpracování obrazu a videosignálu z kolposkopu během konizace

Guidelines:

Design and develop simplified simulator of the colposcope. Perform pilot experiments with simulator. Compare the results (images and video from pilot experiments) from simulated and real colposcope. Design recommendation, how to perform suitable sensing of real operation as regards precisely sensed trajectory of the selected operational tool and how to reconstruct the whole anatomy around the cervix.

Bibliography / sources:

- [1] Carcopino, X. et al., The Accuracy of Large Loop Excision of the Transformation Zone Specimen Dimensions in Determining Volume: A Multicentric Prospective Observational Study, Journal of Lower Genital Tract Disease, ročník 21, číslo 2, 2017, 120-124 s., doi: 10.1097/LGT.0000000000000283
[2] MAYEAUX, E.J., THOMAS COX, J., Modern colposcopy: textbook & atlas, ed. 3, Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health, 2012, ISBN 1608315479

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ABSTRACT

Sensing and processing of the image and video from the colposcope during the conization

Cervical cancer takes on a very large and significant fraction of women healthcare issues globally and thus the development of the colposcope has been rapidly increasing ever since it has been invented and subsequently used in clinical practice. Colposcopy mainly became an important tool in the detection and diagnosis of any abnormalities that may lead to cervical lesions. This thesis focuses on the preparation of a simplified colposcope simulator which would allow for the recording, sensing, and processing of images and videos taken during the procedure of the cervical conization and to perform the suitable sensing of the true path of the trajectory when using the LLETZ operational tool. The work done in this thesis shows a different point of view for the evaluation of the cervical conization operation quality. By time, the diagnosis and treatments of cervical conization will reach stages that nobody could have imagined reaching. In the future, it would be extremely useful to perform the experiments within this thesis in the real operational theaters with some additional sensing devices that will be optimal from the point of view of the dimensions, ability to sense the whole anatomy of the cervix and loop trajectory reliability.

Key words

Cervix

Cervical conization

Colposcope

Phantom

Large loop excision of the transformation zone

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List of symbols and abbreviations

List of symbols

Symbol	Unit	Importance
<i>V</i>	volts	a quantitative expression of the potential difference in charge between two points in an electrical field.
<i>cm</i>	-	a metric unit of length, equal to one hundredth of a metre.
<i>mm</i>	-	a metric unit of length in, equal to one thousandth of a metre.

List of abbreviations

Abbreviation	Importance
LLETZ	Large loop excision of the transformation zone
CCTV	Closed-circuit television
WiFi	Wireless fidelity
LED	Light emitting diode

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1 Introduction

Cervical cancer takes on a very large and significant fraction of women healthcare issues globally and thus the development of the colposcope has been rapidly increasing ever since it has been invented and subsequently used in clinical practice. Cervical conization is a therapeutic process used for the purpose of removing precancerous cells which are an indication of cervical carcinoma. Colposcopy has been around for many years now and for the longest time, colposcopy mainly became an important tool in the detection and diagnosis of any abnormalities that may lead to cervical lesions [1].

The procedure of cervical conization highly depends on an invasive method that uses a Large Loop Excision of the Transformation Zone (LLETZ) in order to get rid of any precancerous cells on the surface of the cervix which produces some complications when recording the whole process of the conization by using some types of video operators. This whole process takes approximately 16 seconds and the conization is then evaluated based on this approach. The invasive process including the Large Loop Excision of the Transformation Zone (LLETZ), which utilizes an electrically heated wire loop, is the absolute most common and effective way of removing cervical tissue targeted with precancerous cells. Because of the invasiveness of the large loop excision of the transformation zone (LLETZ) and the speculum, they both get in the way of obtaining a clean recording [2].

In addition, colposcopy is used to screen and diagnose precancerous cells present in these sites (vulva, vagina, and cervix) before they reach a chronic cancerous stage. The cervix is the inferior extension of the uterus and is divided into two portions. The lower portion (*portio*, or vaginal cervix) extends into the vagina and is the structure that can be visualized after speculum placement. The upper or supra vaginal cervix extends from the vaginal attachment to the lower uterine segment [1]. By inserting a speculum, also known as a gynecological mirror into the vaginal canal, it expands the vaginal walls in order to maintain a clear view for examining the lower portion of the cervix [3]. In order to go through with this procedure, a colposcope is used for the evaluation of any changes that may take place on the cervix. Generally, colposcopy has very few risks, most of the complications actually occur as a result of the conization or the biopsy of the cervix and cellular tissue being taken for diagnosis and these risks include heavy bleeding, infection, and pelvic pain. The colposcope utilizes illuminating light at various magnifications on the cervix. This device furthermore helps and assists the internal visualization of the cervix and any abnormalities in the vagina or on the cervix which can be very difficult to detect with the naked eye [6].

The main dilemma is sensing the trajectory of the Large Loop Excision of the Transformation Zone (LLETZ) via a colposcope by either using a still or video camera. Therefore, the main aim of this thesis is to design and develop a simplified simulator of the colposcope in order to perform and obtain a full-detailed sensing and recording of the whole cervical conization procedure as well as to grant the reconstruction of the whole anatomical structure of the cervix while also performing a suitable sensing of the cervical

conization operation with regards to the trajectory of the operational tool, the Large Loop Excision of the Transformation Zone (LLETZ).

2 Overview of the current state of the art

With time, cervical cancer became a detectable and curable disease. Initially, a diagnosis must be made regarding the presence of the precancerous cells on the cervix. Two types of cytologic specimens may currently be obtained, both taking place by using a speculum and a colposcope. The first type, known as a Pap test, includes an application of the cellular material collected from the cervix directly onto a glass slide which will then be immersed in alcohol and transferred to the laboratory. Another type is a newer liquid processing system which allows for the cellular specimen to be immersed in a solution in order for it to be transferred to the laboratory and then a thin layer would be spread onto a glass slide for detecting the presence of these precancerous cells [1].

2.1 Diagnosing the Cervix

When examining the cervix for any abnormalities, a biopsy may be taken. A biopsy is the process of the removal of small amounts of tissue from the desired area for the performance of an examination under the microscope. Definite diagnosis can only be made from a biopsy. On the other hand, a cone biopsy (conization) can also be done as a treatment for the removal of any precancerous cells that may indicate early stages of cancer. From the cervix, a cone shaped piece of tissue is removed [4].

2.2 The First Colposcope

The colposcope has been around for many years in the medical field. In 1901, it was confirmed by Otto von Franqué that what played a big role in cervical cancer are the abnormalities visible in the cervical tissue. At the university of Bonn in Bonn, Germany, Otto von Franqué employed Hans Hinselmann to work and assist him with the study of the white patch-like abnormalities visible on the surface of the cervix, called leukoplakia, which were visible to the unaided eye and because of that, Hinselmann began researching for a more suitable and better way to view the cervix in order to identify the early stages of cervical carcinoma [5].

Using lenses and an intense light source, the first colposcope has been developed and used in December of 1924 by Hans Hinselmann in Hamburg, Germany. He attached a binocular Leitz dissection microscope on a tripod and this optical system was then attached to a stand in order to move it in many different directions and for adjusting the height and parameters needed. This instrument was capable of magnifying the view of the cervix by the physician in clinical practice. Although the colposcope was first developed in December of 1924, Hinselmann first reported his findings in 1925. In addition to developing the colposcope, he also suggested and defined a classification system for the abnormalities found in the cervix, particularly for the detection of the early signs and stages of cancer; it was then clear that most of the abnormalities took place in

the lower part of the cervix. The metal speculum was also used during the colposcopy to keep the vagina open for the cervix to be easily viewed and accessed [5].

2.3 Colposcopy

Colposcopy is generally used to diagnose abnormalities concerning the female genital organs including genital warts, the inflammation of the cervix, precancerous changes in the tissue of the vulva, the vagina, and the cervix [6]. After the diagnosis of a cellular specimen has been made and the clarification of the presence of the cervical carcinoma, the process of the cervical conization can be followed. Therefore, there is a very wide range of focus regarding the sensing and processing of images and video recording when going forward with the procedure of cervical conization.

2.4 Karl Kaps KP 3000 Colposcope

Considering the rapid innovation and development of both the medical and engineering fields, many technologies have been used in order to sense the cervix and process recordings using the colposcope. For instance, The Karl Kaps colposcope, seen in Figure 2.1, ensures a correct diagnosis due to its optics, multiple zoom levels and first-rate lightning system. The Karl Kaps KP 3000 meets high standards of quality in medical clinical practice. It is very mobile and flexible which makes handling it very simple. The magnification factor of this colposcope comes is a 3 step-changer of 0.63, 1.0 and 1.6 which allows for a better, sharper and much cleaner quality when used in examination. Furthermore, with regards to the optics, both straight tubed and incline tubed options may be used. As for obtaining a recording, a special adaptor and camera can be integrated for the purpose of sensing and recording in clinical practice and for creating a diagnosis. An integrated beam splitter with c-mount, a special adaptor, is suitable for the use of analog and digital cameras and the Kaps HD video camera used for findings and documentation. For the human eye, it is exhausting to use colposcopes for long term visualization and interpretation. Therefore, the Kaps HD video camera is a technical additive which makes it much easier and less exhausting for any recording that needs to be documented by using the colposcope. It allows both pure observation and documentation [7].



Figure 2.1: Kaps KP 3000 colposcope [7].

2.5 POCKeT Colposcope

One of the newest and modern approaches for the screening and detection of cervical carcinoma is the use of the so-called Pocket Colposcope (POCKeT) found in Figure 2.2. From its name, Pocket, it can be furthermore understood that it is a small miniature version of a colposcope, plus, it is low cost and an easy to use portable colposcope. A Pocket Colposcope (POCKeT) grants healthcare providers the ability to zoom and capture images with the simple click of a button and it can be used both with and without the presence of a speculum. This device has a camera at the tip and a consumer grade light source which provides a live image or video of the cervix [8]. A Pocket Colposcope (POCKeT) can be easily comparable to that of a state-of-the-art digital colposcope with the concept of it being similar to a gynecological ultrasound transducer which can be inserted into the vagina at a closer distance than that of a typical traditional colposcope [9].



Figure 2.2: POCKeT colposcope [8].

2.6 Self-Examine Colposcope/Mini Camera

The Self-examine colposcope/mini camera, Figure 2.3, is another device that has been recently floating the market. It is a self-examine mini colposcope that is used to examine and diagnose any abnormalities present in the cervix. This handheld colposcope is designed specifically to make it easier for women who may not be so secure with going to visit the gynecologist for an examination and would rather do it by themselves. It is very user friendly and extremely practical and easy to use. Two disposable plastic speculums with different sizes are also provided which can directly be attached to and placed on the hand-held colposcope for an easier use with regards to any self-examination being performed. The small speculum is used for nulliparous females while the middle speculum is used for natural birth females. It is battery operated and uses an SD card for the documentation and storage of the captured desired pictures. A catalog is also provided to help the person using it identify the cervix on whether it is normal or if any abnormalities are present [10].



Figure 2.3: Self-examine colposcope [10].

2.7 MobileODT's Eva System Colposcope

A similar device, MobileODT's Eva system which can be seen in Figure 2.4, is a mobile hand-held contact-less image capturing colposcope capable of auto focusing and 16x optical magnification that is able to achieve high quality images and videos. It works by using online data management in order to document accurate diagnosis and locate the biopsy which then simplifies the whole screening and recording process. The online data management also allows for easy access and securely sharing patient information between medical personnel [11]. The Eva system uses a green filter within the colposcope to present the images. A green filter is commonly used in colposcopy in order to highlight blood vessels in the tissue and it enables a clear identification of any disease. This helps and eases the identification of the blood vessels within the cervix since blood has a red color because it reflects red but absorbs both blue and green. Producing this digital green filter can be done in three ways; filtering illumination, filtering the light on collection, and the manipulation of the image. It also requires the intensity of the green light (500-570 nm) to be higher compared to the blue and red light [12].



Figure 2.4: MobileODT's Eva system colposcope [12].

2.8 Vidan[®]2 Video Colposcope

Another innovation, the first integrated HD video colposcope with a touchscreen monitor, Vidan[®]2 is a very mobile and flexibly adjustable colposcope attached to a gynecological examination chair with great technology in image quality when it comes to zooming, both

autofocus and manual focus, displaying, and green light which was discussed above as being an important parameter for an improved visualization of the vascular structure and the blood vessels around the cervix. This video colposcope can be found in Figure 2.5 below. Another perk is that the results obtained from the examination taking place using the vidan[®]2 can be backed up and documented very quickly and easily. The system is completely autonomous without the requirement of using any other monitor and allows for the smallest of details to be viewed and displayed with up to 42x optical zoom [13].



Figure 2.5: Vidan[®]2 Video Colposcope [13].

3 Aims

The main aim of this thesis is to design and develop a simplified simulator of the colposcope in order to perform and obtain a full-detailed sensing and recording of the whole cervical conization procedure as well as to grant the reconstruction of the whole anatomical structure of the cervix while also performing a suitable sensing of the cervical conization operation with regards to the trajectory of the operational tool, the Large Loop Excision of the Transformation Zone (LLETZ).

This can be achieved through the following steps:

- Preparing different models of the cervix
- Designing and developing a simplified simulator of a colposcope with video operators (camera and lens)
- Reconstructing the whole anatomical structure around the cervix
- Preparing the Large Loop Excision of the Transformation Zone (LLETZ) model and evaluating the true path of the trajectory

3.1 In depth steps for achieving the aim

For the first step, it is important to have a phantom of the cervix and the vaginal canal, ideally made from foam because it will be the best and closest phantom when compared to the structure of a real cervix.

For the second step, it is necessary to design, test and validate a simplified simulator of a colposcope with video operators for the direct recording of the conization process from the colposcope simulator itself.

The third step involves different methods for the reconstruction of the whole anatomy of the cervix which would be used and compared to conclude the best method for achieving this type of cervical reconstruction.

At last, performing a detailed recording sequence and capturing images of the whole conization procedure with the help of the speculum and the Large Loop Excision of the Transformation Zone (LLETZ) model which is the operational tool used for the conization procedure.

4 Methods

To fulfill the aims of this project, the phantom is the first and most crucial step for experimenting. Many different approaches were considered and used for creating a simplified colposcope model, reconstructing the whole anatomy of the cervix and sensing the trajectory of the LLETZ loop across the cervix.

4.1 Designing the phantom models of the vaginal canal and cervix

Creating the first phantom was done by using foam which was the ideal option for the closest representation of the cervix and vaginal canal. It is very important to make sure that the parameters of the phantom match with the parameters of the real-life anatomy of the vaginal canal and cervix. In general, there is a relatively wide dimension range of the cervix. The general model is a conical cone shape which ideally measures 2.5 cm in width and 2.5 to 3 cm in length. The vaginal canal however has a measurement of about 8 cm.

The foam is very pliable and flexible for the speculum to be inserted and adjusted for viewing the cervix with the help of the colposcope. After using scissors to make a cut vertically on the surface of the cylindrical piece of foam, it was then hollowed out which resulted in a phantom of the vaginal canal. A cone shaped piece of foam was then shaped and molded to represent the cervix which is also painted red by using a marker and then stuck using a foam bonding glue to the back of the foam tube. By using such a structure, the whole phantom acted as a representation for the cervix and vaginal canal. This phantom model of the cervix can be seen below in both Figure 4.1 a and Figure 4.1 b.

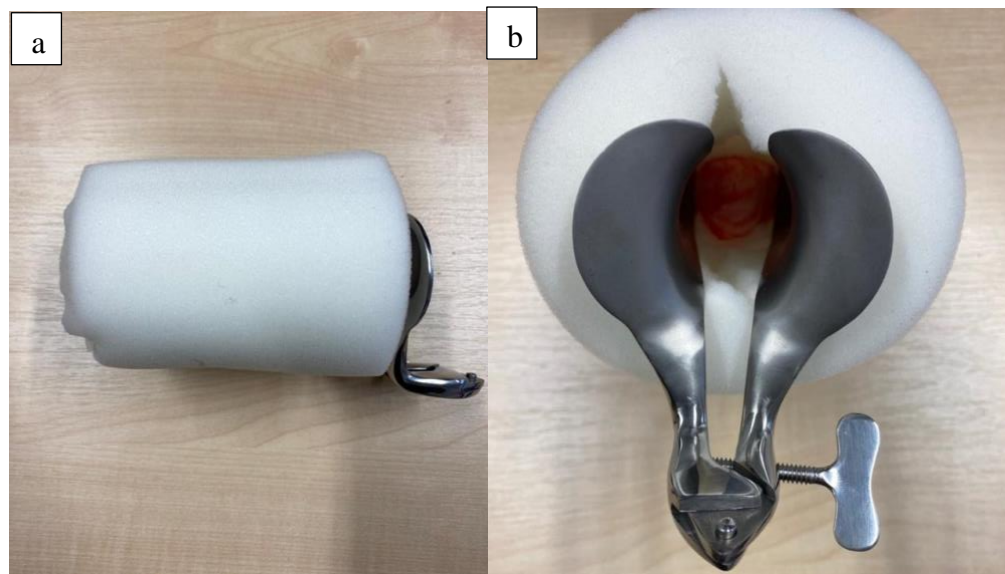


Figure 4.1 a and b: Outer and inner view of the phantom model with inserted speculum [photo - author].

The second phantom of the cervix and vaginal canal was done on a larger piece of foam which mimicked the smaller phantom. It is done on a larger scale for the purpose of seeing whether it is possible to obtain a different outcome when experimenting with the stimulated colposcope and for the purpose of the reconstruction of this anatomical part. A large piece of cube foam is hollowed out at the center, seen in Figure 4.2, to mimic the vaginal canal and a small area was hollowed out within it to hold a cylinder cone shaped piece of foam and a cube shaped piece of foam which acted as the cervix. It was mostly done by using scissors and an electrical foam cutting tool.

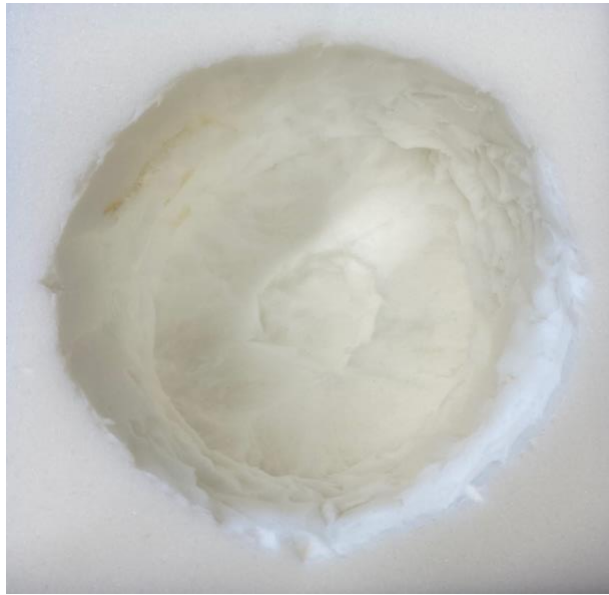


Figure 4.2: Hollowed out area to mimic the vaginal canal and smaller area holding the phantom cervix in place [photo - author].

Two different cervix phantoms are designed using foam as seen in Figure 4.3 below. One is prepared in a cone shape and the other a cube shape. Lines were drawn on both the cervix phantoms to distinguish and determine the sides and positions when looking at any images taken for the purpose of sensing and reconstruction.



Figure 4.3 Side view of both the cube shaped and cone shaped cervix [photo - author].

4.2 Using the speculum

The speculum was inserted into the phantom to mimic a similar approach done in clinical practice to expand and hold the vaginal walls apart for viewing and reaching the cervix.

Both speculums in Figure 4.4 are metal, the only difference between them is that the blue one has a special channel built for the smoke to escape during the cervical conization using the LLETZ. Since the LLETZ is considered an approach for the conization, the tube which can be seen on the blue speculum in Figure 4.4 below allows for the smoke to escape so that the physician can see the cervix without the smoke being trapped and disrupting the view of the cervix by the conization being performed. The silver one is used for any other procedure which does not involve conization such as any type of analyzing and diagnosing.



Figure 4.4: Metal speculums. The blue one used while proceeding with conization because it has a smoke escape channel which helps with the elimination of smoke. The silver one used for regular diagnosing [photo - author].

4.3 Designing the background regulator

A background regulator plays a role in determining the position of each image after it has been taken. It is used to define dimensions as well as to regulate the structure of the cervix. It levels out the position of the cervical phantom and distinguishes the different sides once the sensing has been done.

The background regulator is made by drawing equal vertical and horizontal lines onto two pieces of hard paper. Calls of about 4 cm in width and height were obtained. The two hard paper pieces were then glued together to make a singular continuous piece. This is done so that the background regulator would be mended into a cylinder for the purpose of fitting it into the vaginal canal model. Across each column, different symbols were drawn. This signifies the different positions and angles of each image that would then be taken. The background regulator placed around the cone shaped cervical phantom can be seen in Figure 4.5.

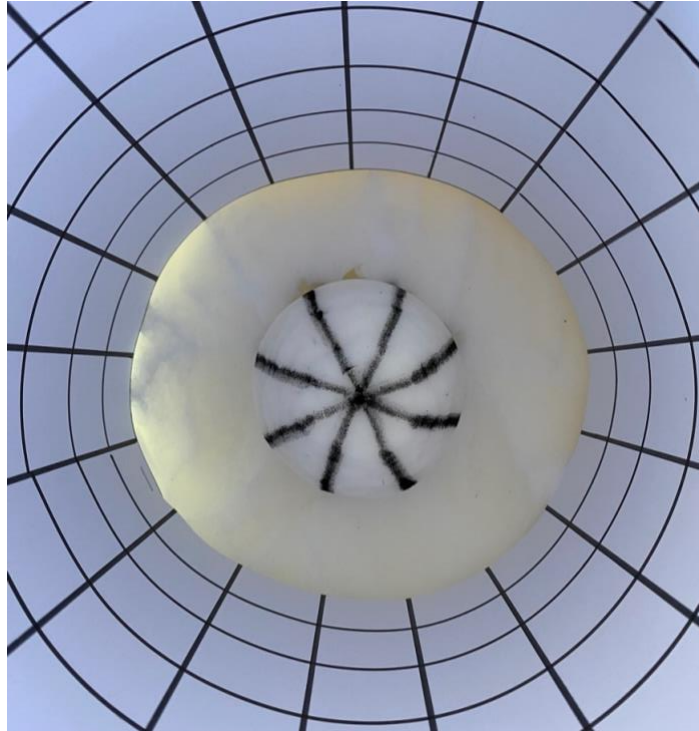


Figure 4.5: The cone shaped cervical model placed within the background regulator after shaping [photo - author].

Across each column on each cell, different symbols are drawn. This signifies the different positions and angles taken into account of each image that would be captured and then used for sensing.

4.4 Using the Self-Examine Colposcope/Mini-Camera

The self-examine colposcope/mini camera was the first colposcope used in this experiment. It can be seen in Figure 4.6. This handheld colposcope is connected to a monitor in order to record, capture images and view the cervix. Two disposable plastic speculums with different sizes are also provided that can directly be attached to the handheld colposcope. Batteries were inserted since it is battery operated and an SD card was used to store the captured desired pictures. It was then connected to the monitor for the purpose of viewing.

The only way to view the cervix using this self-examine colposcope is by connecting it to a monitor. The bigger speculum, used typically for women who went through natural childbirth, was used on the hand-held colposcope since it was a better fit for the phantom. The speculum attached to the colposcope was then turned on and inserted into the phantom. The light was on for the purpose of clearly viewing the cervix through the monitor. After examining the cervix, desired pictures were captured.



Figure 4.6: Self-examine colposcope/mini camera with plastic speculum [photo - author].

4.5 Using the Karl Kaps Colposcope KP3000

The phantom model of the vaginal canal and the cervix was then viewed by the Karl Kaps colposcope KP3000 which can be seen below in Figure 4.7. It allowed the phantom to be seen from a medical perspective. First, the colposcope was used without the special adaptor, integrated beam splitter with c-mount, and the Kaps HD video camera for the purpose of examination. The colposcope was set to the ideal distance from the phantom which is a very important parameter in diagnosis.

The distance between the colposcope and the phantom relies on both the distance of camera from the cervix plane which is approximately 40 cm and the distance of the colposcope lens from the surface of the phantom which is approximately 25 cm as seen in Figure 4.8. Regarding the magnification, the most standard and generally used in clinical practice is 0.65 which was also the magnification used in the entire performance of the experiment using the colposcope. The whole purpose of colposcopy is the evaluation of color and the small area around the cervical canal and not to evaluate the volume shape of the whole surface hence the reason why the view of the phantom cervix is 2-dimensional.



Figure 4.7: Karl Kaps colposcope KP3000 [photo – author].



Figure 4.8: Karl Kaps colposcope KP3000 and view of the phantom model [photo – author].

4.6 Added accessories to the Karl Kaps Colposcope KP3000

After examining the phantom cervix without the added accessories, the lens of the colposcope was taken apart in order to add the integrated beam splitter with c-mount,

Figure 4.9 a, and to attach the Kaps HD video camera, Figure 4.9 b, for the purpose of recording and sensing. Without these accessories, the colposcope can be only used for diagnosing and not for recording.



Figure 4.9: a) Integrated beam splitter with c-mount and b) Kaps HD video camera [7].

The special adaptor is attached to the colposcope for the optimal recording of the cervix. The colposcope is then attached to a monitor in order to view the recording obtained from the experiment being conducted. After the attachment of the integrated recording camera device onto the colposcope, a live recording of the phantom with the vaginal canal and the cervix was achieved. The focus and magnification can be controlled and adjusted to the appropriate parameters for a better visualization as well as for a more accurate colposcope sensing. The same magnification, 0.65, and distance were still used for this part of the experiment.

4.7 Designing the simplified colposcope model

Now that we have a better understanding of a colposcope and how it operates, the colposcope simulator can be designed. The requirements for a simplified simulator structure of the colposcope are the flexibility of position (x, y and z settings), zoom (magnification), step regulation (lightening/light source) and most importantly capturing and sensing images and video recordings (camera).

4.7.1 Simplified colposcope model

The idea of a simplified simulator structure of the colposcope corresponds to the following.

An adjustable SONY VCT-D680RM tripod is used as the stand. It expands from 19" to 57". The height is adjustable, and it has a wide rotation angle which in this sense is a very close replica for a colposcope stand. It is movable in all directions in which obtains the different angles and positions a colposcope can obtain. The flexibility of position can be attained from the x, y and z settings.

A CCTV lens and an Attez WiFi camcorder are integrated together. The original lens in the camcorder obtains images in a wider view which merits the need for a more precise and narrower angle hence why it was replaced by a CCTV lens which will result in a more precise view since it is capable of monitoring a limited area. The disassembly of the Attez WiFi camcorder can be seen in Figure 4.10. The Attez WiFi camcorder is portable and can be connected to an app of the phone which makes it easier to capture pictures, record videos, and download the data directly onto the smartphone. The angle of view, level of zoom and focal length of this CCTV lens in particular can be adjusted and set to the desired format.



Figure 4.10: Integration of the CCTV lens and Attez WiFi camcorder [photo – author].

Since the Attez WiFi camcorder can be connected to a smartphone, the images are easily captured and stored onto the mobile device without any issue. This makes the collection of images quicker and easier hence why this camcorder was used for experimenting. By using the Attez application on the mobile phone, this CCTV lens integrated camcorder can capture images as well as record videos which plays a major role in this case for the purpose of sensing and recording the area around the phantom of the cervix.

A Proxxon XY micro translation stage (1 turn = 1mm) [14] is used on the tripod as a base for the CCTV lens and camcorder. This stage is also used for a better precision and focus when sensing the phantom of the cervix. If any adjustments need to be done regarding the sharpness of the image, the micro translation stage will help in adjusting.

In addition, two LED flashlights (300 lumens) [15] are placed on either side of the sensing device which act as the light source similar to the light source on a colposcope. The light source on the flashlights can be manually zoomed in or out depending on how precise the light being emitted needs to be. The diameter or aperture can be changed and adjusted in this colposcope simulator but cannot be done so in a colposcope.

The complete simplified colposcope simulator model can be seen in Figure 4.11 and Figure 4.12. The adjustable tripod is seen as a stand carrying all the other relevant

parts which include the XY micro translation stage [14]. Above the micro translation stage, the attachment of the supporting box for the CCTV lens and the Attez WiFi camcorder with the LED flashlights [15] placed on either side of this integration can be seen.



Figures 4.11: Simplified colposcope model [photo – author].



Figures 4.12: View of the simplified colposcope model being used on the phantom of the cervix [photo – author].

4.7.2 Different approaches of the simplified colposcope model

Four different approaches were taken into consideration. They involve the attachment of the CCTV lens and Attez WiFi camcorder and a flexible LED lamp with a clip onto a colposcope stand. The flexible LED lamp is the ideal option for this kind of simulator because it can move in all directions and has a free angle. This allows for the use of the light source for different heights and angles. The clip can be implemented and attached on any part of the colposcope stand. The light from this lamp acts as a light source the same way the light source in a colposcope is used for medical implementation. This gave an accurate representation of a clinical diagnostic colposcope.

Two different flexible LED lamps were used for the simulator. Both have an adjustable light and have the ability to be clipped onto any part of the colposcope stand. The only difference between them is the height of the adjustable neck that connects to the bulb. The first flexible LED lamp [16], Figure 4.13 a, that was experimented with has an adjustable height of 20-35 cm. The same CCTV lens and Attez WiFi camcorder integration as well as the supporting box that were used of the colposcope simulator were implemented onto the Alltion colposcope stand. The LED lamp was then clipped on the side of the supporting box and aimed towards the cervix phantom. The images were then captured by using the Attez application on the mobile phone. The second flexible LED lamp [17], Figure 4.13 b, that was used has an adjustable height of 40-63 cm and a terminal range of 1-27 mm. Once again, the same CCTV lens and camcorder integration were used. The only difference with this LED lamp is that it was clipped onto the side of the Alltion colposcope stand instead of clipping it to the supporting box where the CCTV lens and camcorder lay.

Another approach was considered, this approach involved the use of both the LED lamps, Figure 4.13 c, at the same time. When this was done, the light source was twice as bright, and the images came out clearer. At last, the integration which includes the two flashlights, supporting box, CCTV lens, camcorder and XY micro translation stage, made for the colposcope simulator in 4.7.1 above was implemented onto the Alltion colposcope stand. This last integration can be seen in figure 4.13 d.

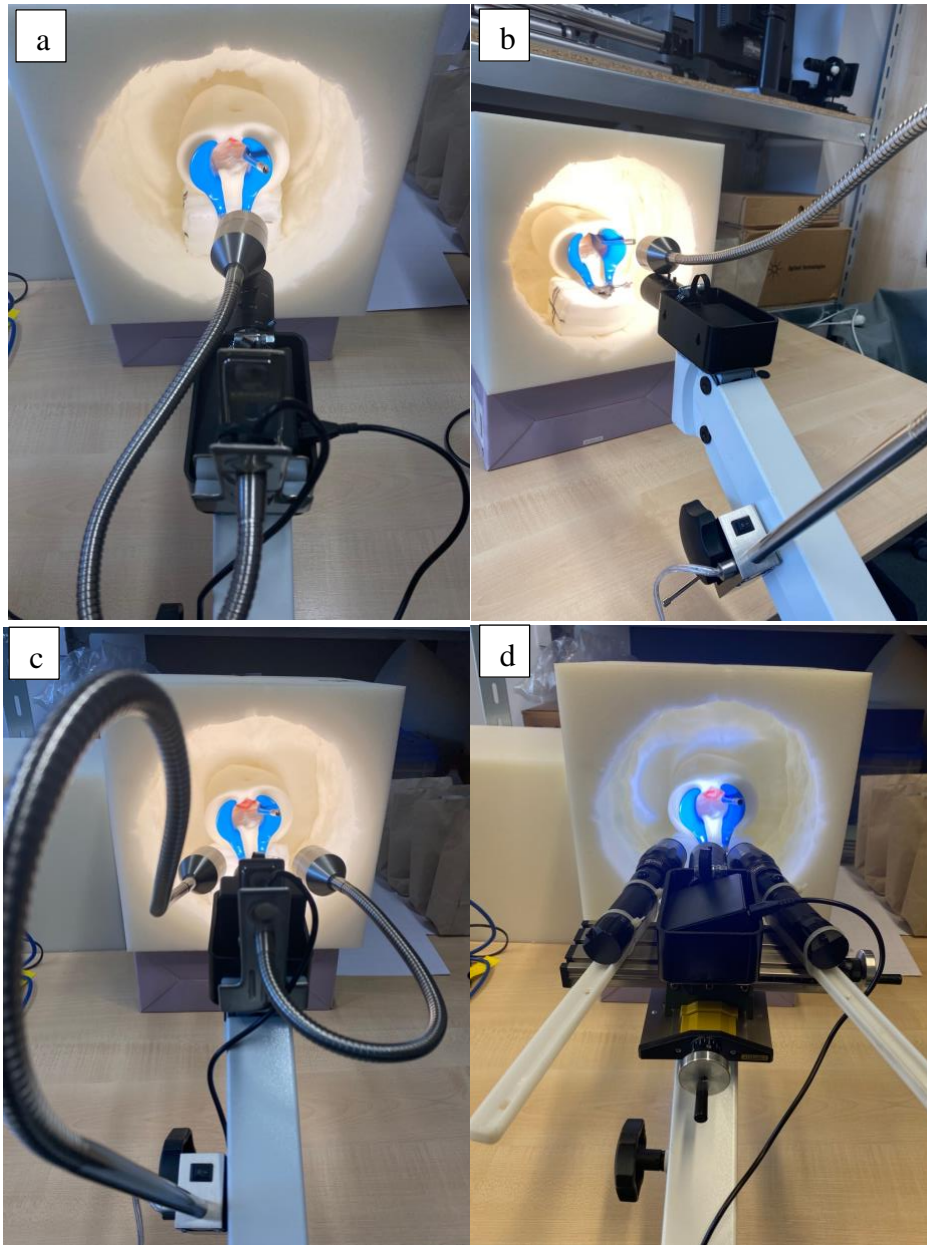


Figure 4.13: Implementation of the supporting box and the CTTV lens camcorder integration onto the Alltion colposcope stand with the light source of the a) short [16], b) long [17], c) both flexible LED lamps and d) LED flashlights [15] [photo – author].

4.8 Reconstructing the anatomy of the cervix

Two different approaches were considered for the purpose of reconstruction. The first approach is capturing multiple images with different angles of the model of the cervix and the background regulator by using a mobile phone (iPhone 11, OS 14.7.1) and stitching the images to create a panorama by using MATLAB. The second approach is using a fisheye lens to capture a singular image of the cervix model and background regulator and then transform this image from fisheye to a panorama via MATLAB. The

end goal of both these approaches is to attain a clear reconstruction of the whole anatomy of the cervix model.

For the first approach, panoramic image stitching, the first step was to capture an array of multiple images with some overlapping. This was done by using a smart phone (iPhone11) camera. After the images were captured, they were all adjusted to fit the right dimensions similar to the dimensions used in the m script which in this case is 640×480 . This is done to ensure the correct implementation of this m script. The first set of images are images taken horizontally from left to right with overlapping (Figure 4.14 a). The second set of images were taken on the peripheral along the parameter around the cervix (Figure 4.14 b). Both sets of images were read using the same m script. The m script used and enhanced can be found in appendix A [18].

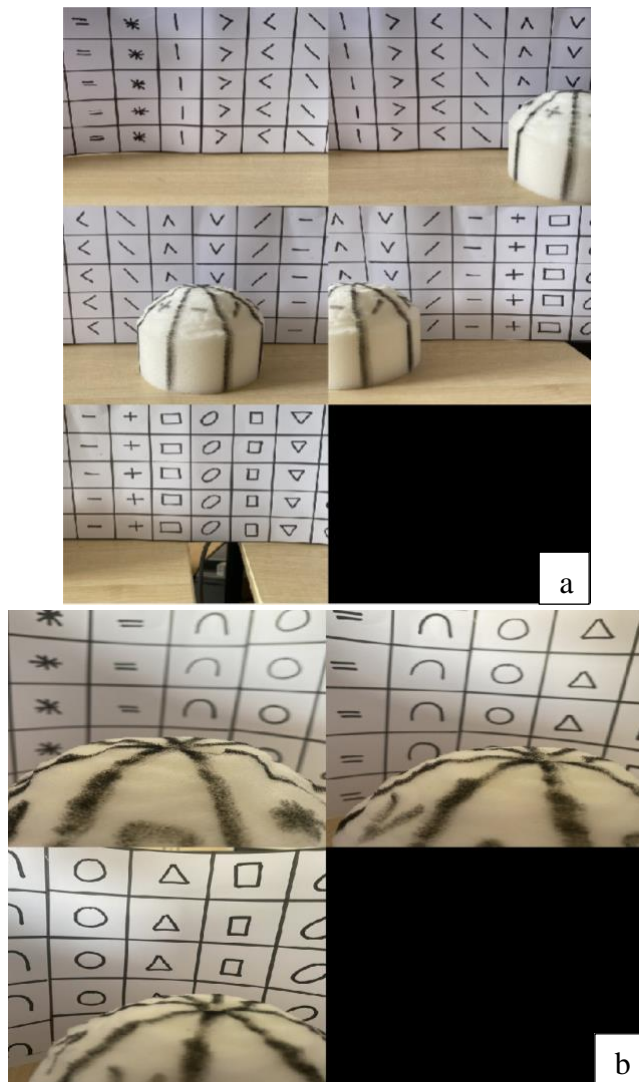


Figure 4.14: a) first set of images and b) second set of images of the cone shaped phantom and background regulator for panoramic stitching [photo – author].

The second approach involves the use of a fisheye lens. A fisheye lens is considered an ultrawide-angle lens which is capable in producing a strong visual distortion with the target of generating a wide panoramic or hemispherical image. These

kinds of lenses can achieve wide angle views. It gives images a characteristic convex non-rectilinear appearance [20]. The idea is to capture a single to view image of the desired cervix by using this fisheye lens. The image shows a clear observation of the whole circumference of the cervix.



Figure 4.15: Fisheye lens [19] [photo – author].

A grabbing device, Blackmagic shuttle, used for digitization in order to process images from an analog to digital module as well as a TFT-LCD-small monitor for capturing and processing the image were used alongside the fisheye lens as seen in the box diagram below. Blackmagic media express is the software that was used for capturing the images taken using the fisheye lens.

The block scheme in Figure 4.16 below shows an accurate representation of the way all the devices were connected and used for the purpose of processing the images taken using the fisheye lens.

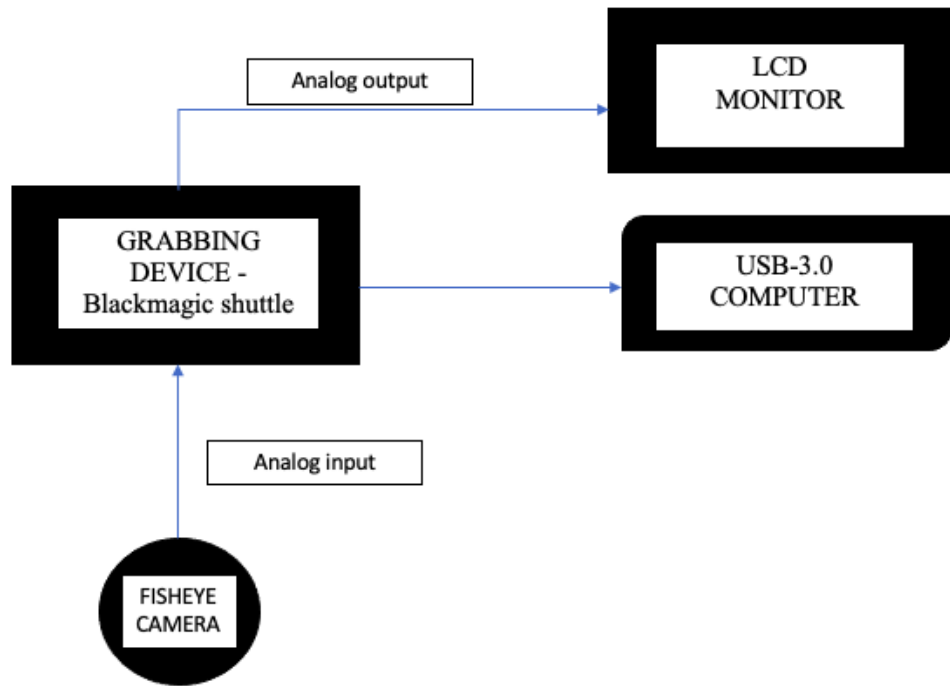


Figure 4.16: Block scheme of the real connection between the Fisheye lens (camera), grabbing device, LCD monitor and the computer.

The image captured by the fisheye lens was then changed to the desired dimensions for it to be compatible with the m script used for the purpose of transforming the image from fisheye to panorama. The dimensions of the capture image were set to 1920×1080 . Three different images were used for this method of reconstruction experiment. Figure 4.17 a is of the cervix phantom with inserted speculum, Figure 4.17 b is the cone shaped cervix phantom and at last, Figure 4.17 c is the cube shaped cervix phantom. After the process of obtaining and changing the dimensions of said image, it is then read by an m script which transforms images from fisheye to panoramic view. The m script used and enhanced can be found in appendix B [21].

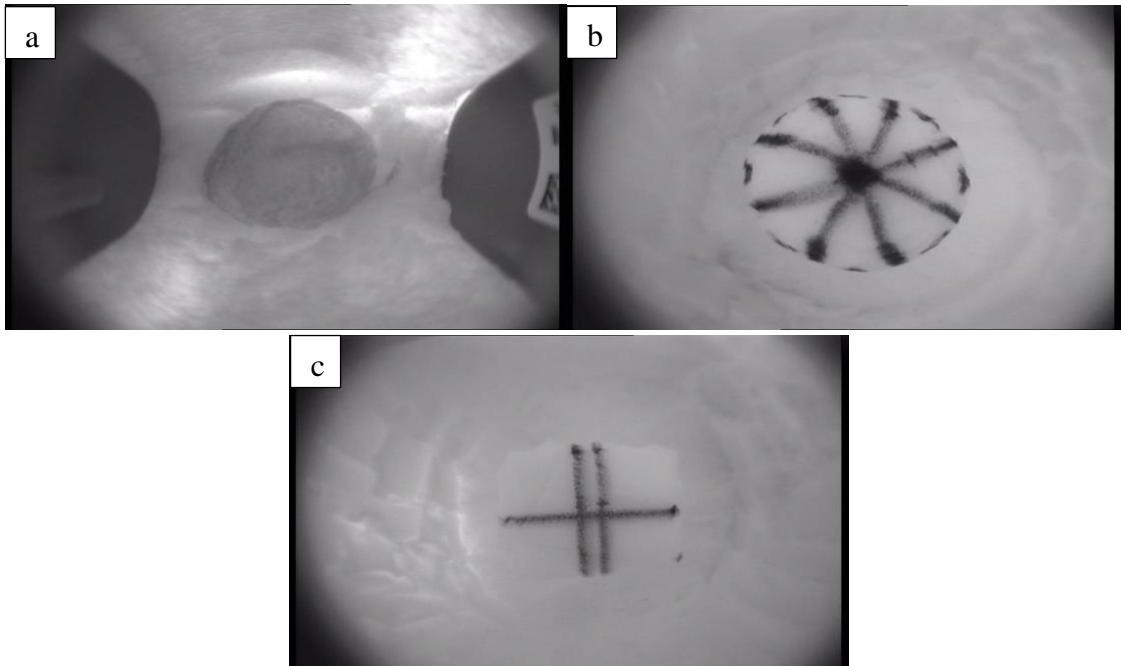


Figure 4.17: Fisheye image of the a) cervix phantom with inserted speculum, b) cone shaped cervix phantom and c) cube shaped cervix phantom [photo – author].

4.9 Preparing LLETZ model for sensing of the trajectory

As for the preparation of the LLETZ model, two wooden sticks were held together via a wire in the shape of a dome which were connected to mimic an actual operational LLETZ. It was all glued and held together as seen in Figure 4.18 a. Using the colposcope, the speculum was switched to the blue one which allows the smoke to move out of the canal when using the LLETZ for the cervical conization in practice. The speculum was inserted into the phantom and screwed open until the desired size of the vaginal canal opening was reached.

The pathway of the LLETZ loop was mimicked by the model that was prepared as seen in Figures 4.18 b and c below. The model is inserted straight into the vaginal canal held open by the speculum onto one side of the cervix. After that, it is moved horizontally across the cervix in order to obtain a biopsy of the cervix. This imitates the trajectory of the LLETZ when used for the operation of the cervical conization.

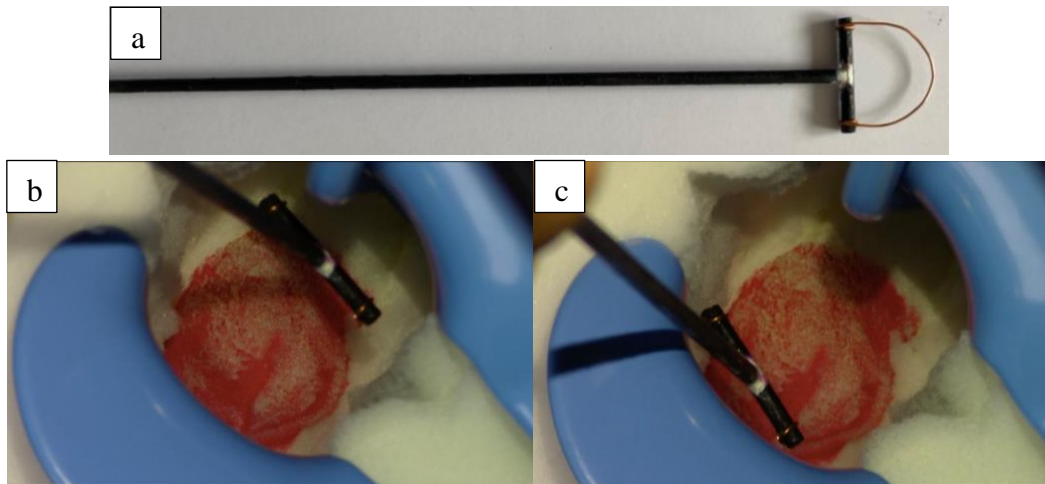


Figure 4.18: a) LLETZ model, b and c) mimicking the path of the cervical conization procedure starting from left side and moving to the right [photo – author].

Another approach is used for having a better understanding and view of the conization procedure. Two OSG5DA7331A high luminous 1.8mm pure green LEDs [22] seen in Figure 4.19 a, were soldered in a closed circuit with an input voltage of a 9V battery. This circuit is then attached onto the LLETZ model with the help of semi conducting tape. The anode and cathode can be distinguished by the length of the leads on the diode. The longer lead is the anode which has a positive connection (red wire) and the shorter lead is the cathode which is a negative connection (black wire). After soldering, the wires are twisted around the base of the LLETZ model and held by semiconducting tape. The LEDs act as position sensors for the trajectory of the LLETZ model. Figure 4.19 b and c below show the whole integration of the circuit onto the LLETZ model.

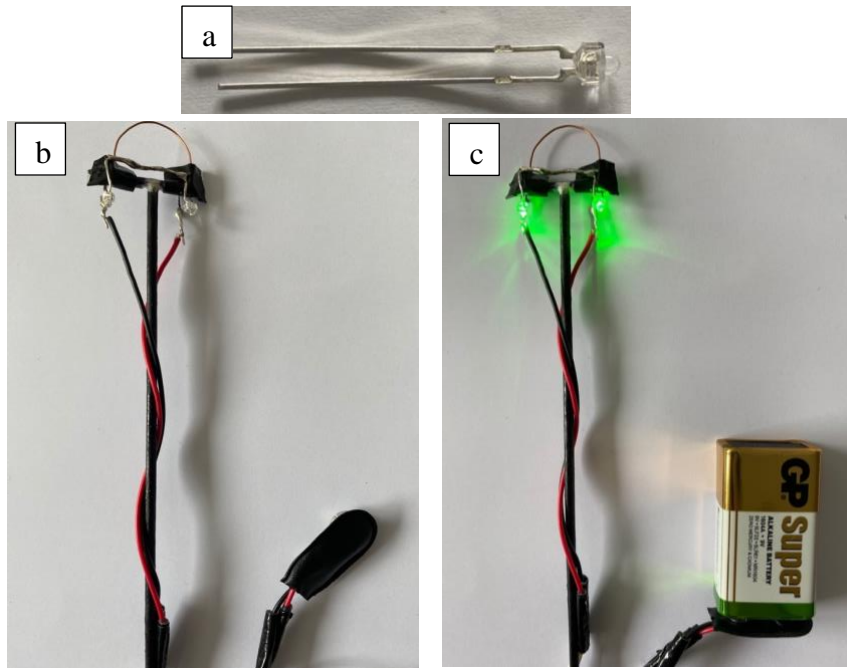


Figure 4.19: a) OSG5DA7331A – 12V high luminous 1.8mm pure green LED [22], b) circuit with two soldered OSG5DA7331A- 12V high luminous 1.8mm pure green LEDs attached to the LLETZ model and c) lit up after connecting to a battery [photo – author].

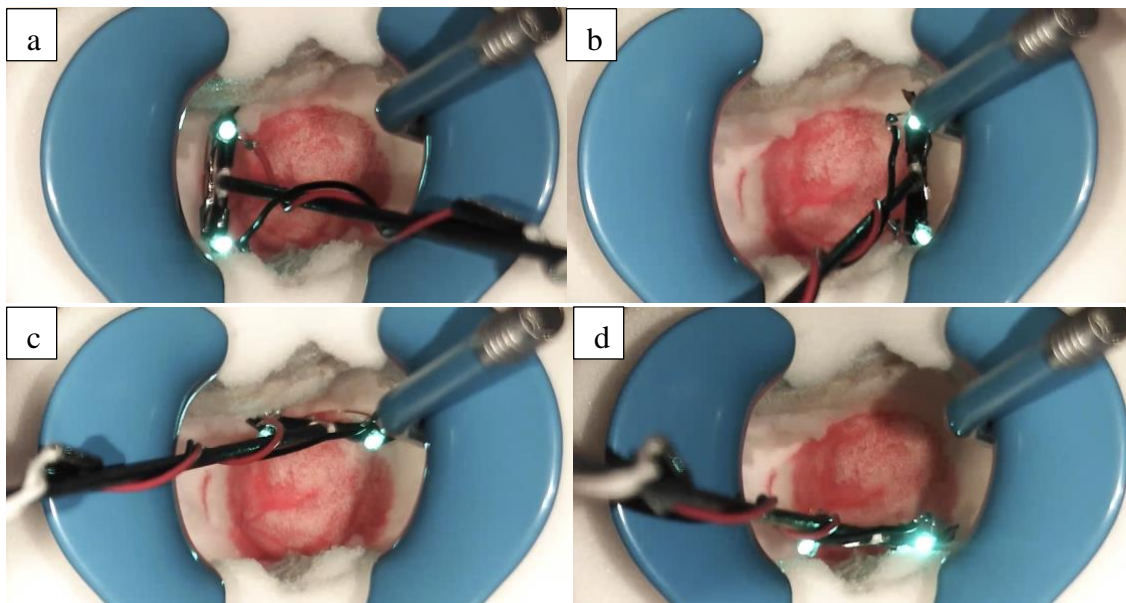


Figure 4.20: LLETZ model on the a) left position, b) right position, c) top position and d) bottom position [photo – author].

For sensing the path of the trajectory of the LLETZ loop model across the cervical phantom, four different videos of the trajectory were recorded by using the colposcope model. The LLETZ model moves in the direction from left to left (Figure 4.20 a), right to left (Figure 4.20 b), top to bottom (Figure 4.20 c) and bottom to top (Figure 4.20 d). After securing the video recordings, the first approach was creating an m script for the semiautomatic sensing of the trajectories and the second approach for an automatic sensing of the trajectories. The semiautomatic approach would consist of three m scripts

where one shows the trajectory of each LED behaving separately, the second m script shows the behaviour of the two LED trajectory path together and the third m script shows the behaviour of both LEDs in a ZIG ZAG pattern. All three m scripts can be found in appendix C (semiautomatic – one LED) appendix D (semiautomatic – both LEDs), appendix E (semiautomatic – ZIG ZAG) and appendix F (automatic – one LED).

Since a video is a sequence of static images in time therefore it is required to read and process every frame as a single matrix sequentially. This would allow the sensing of evaluation of both green LEDs found on the LLETZ loop model. By this evaluation, the coordinates (centre) of both green LEDs can be obtained which will then allow for the true trajectory path to be acquired. The m scripts secure both x and y coordinates for every frame. After the coordinates are obtained, the true path of the trajectory of the LLETZ model moving across the cervix can be plotted for every case of the different directions of the movement of the operational tool model.

The process of video frame processing was done by the following. Within the segmentation of every video frame, the Matlab function `segmentImage` was used. This function manually sets threshold with respect to the selected video file, mask creation, binary morphological operation, i.e. open mask - erosion followed by dilation, this removes foreground. Objects which are smaller than the structuring element that was set using the `imopen` function and the clearing of borders is done using conditional dilatation. The evaluation of the LEDs centers which are very important for the trajectory is based on the Hough transform. All these above-mentioned functions were matched to the selected video file and after that, they were exported as the relating m scripts that were used as functions. The solution of the evaluation of the same center along the trajectory due to the second LED appearance, i.e. second center, was solved by the condition of the maximum possible changes of the coordinates, i.e. < 100 (there is difference for the movement from T to B/B to T and R to L/L to R). The segmentation procedure is done on an application called Image Segmenter – Segmentation within MATLAB. The process can be seen in Figure 4.21 up to Figure 4.26 below.



Figure 4.21: Loading the images.

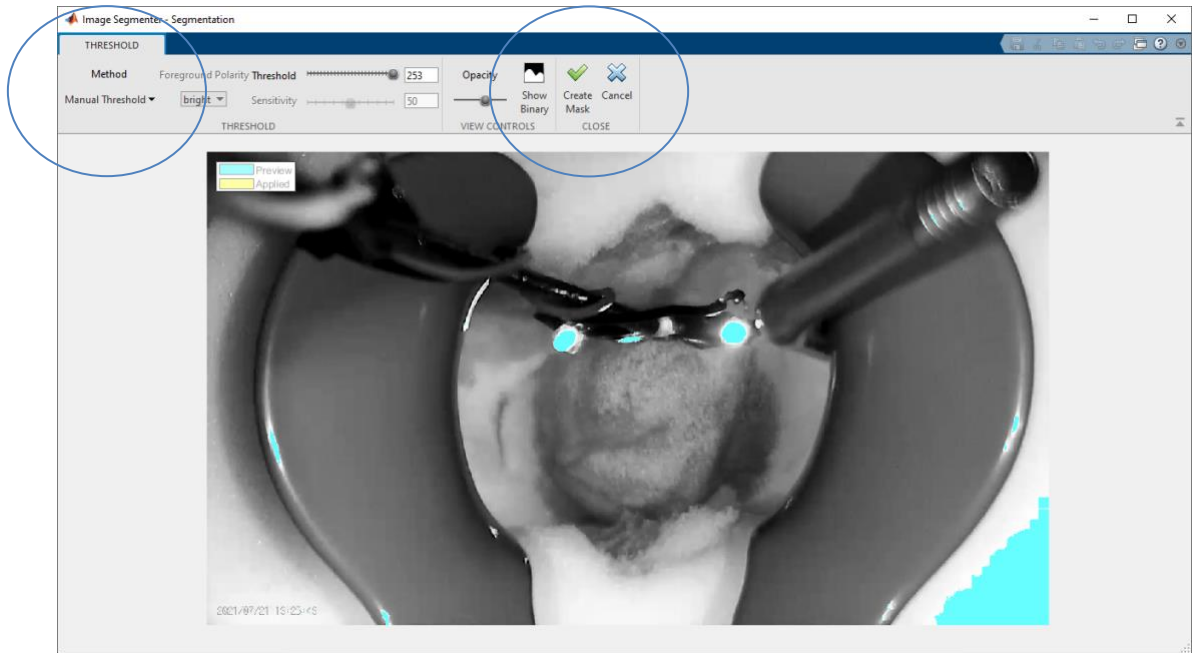


Figure 4.22: Manual threshold settings.

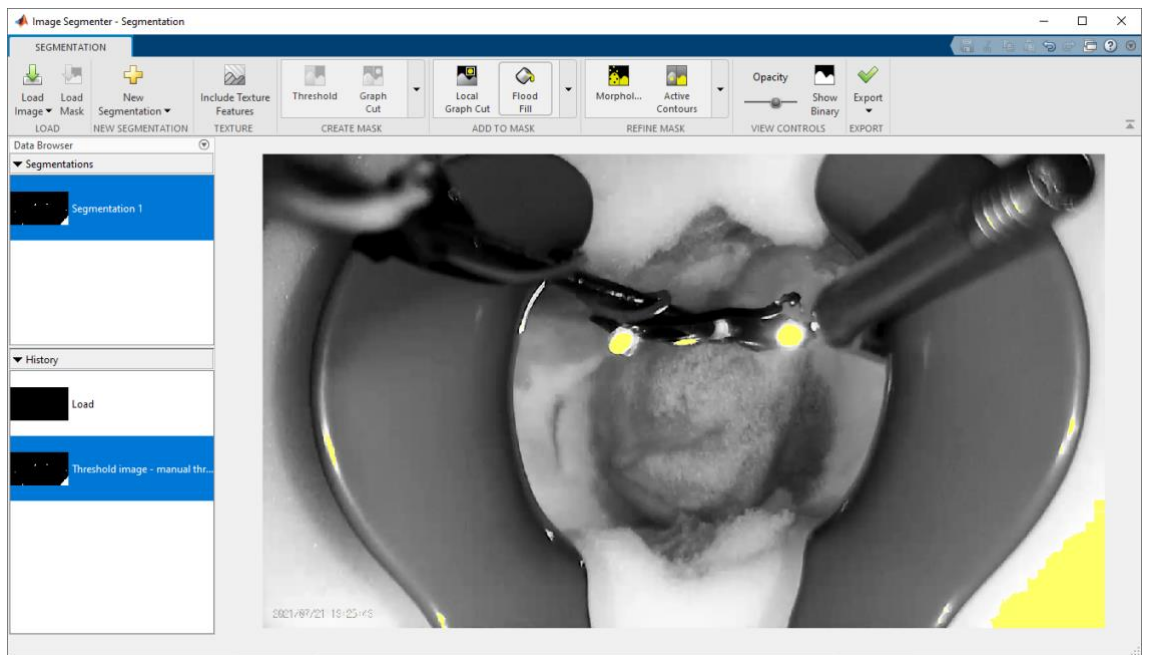


Figure 4.23: Mask creation.

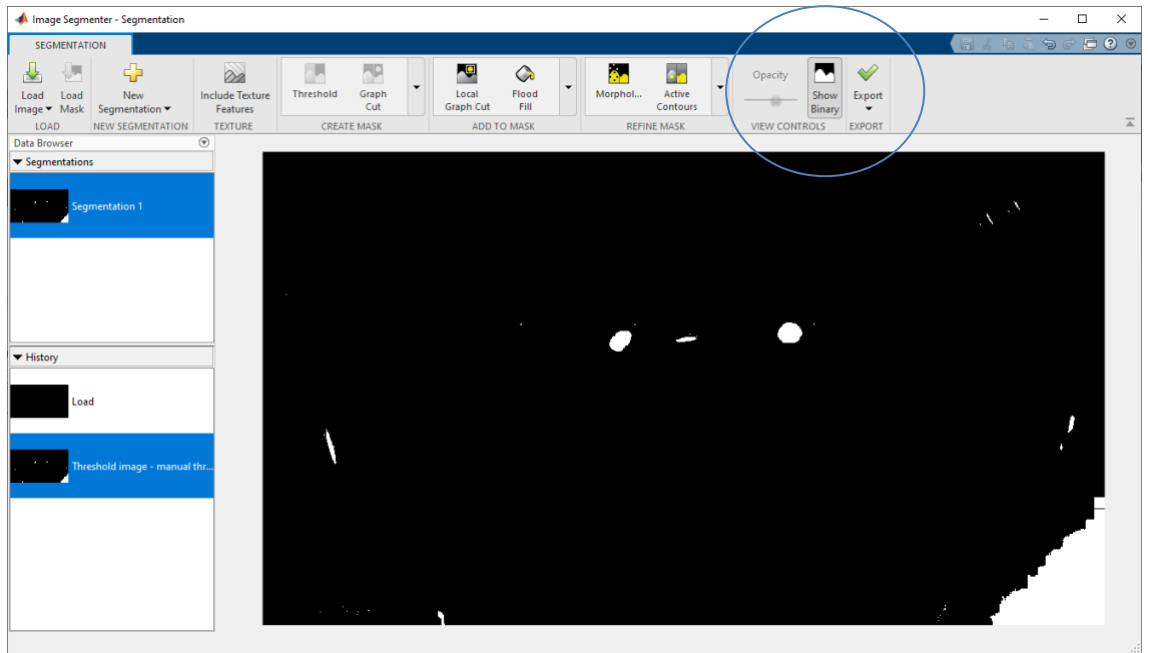


Figure 4.24: Binary image.

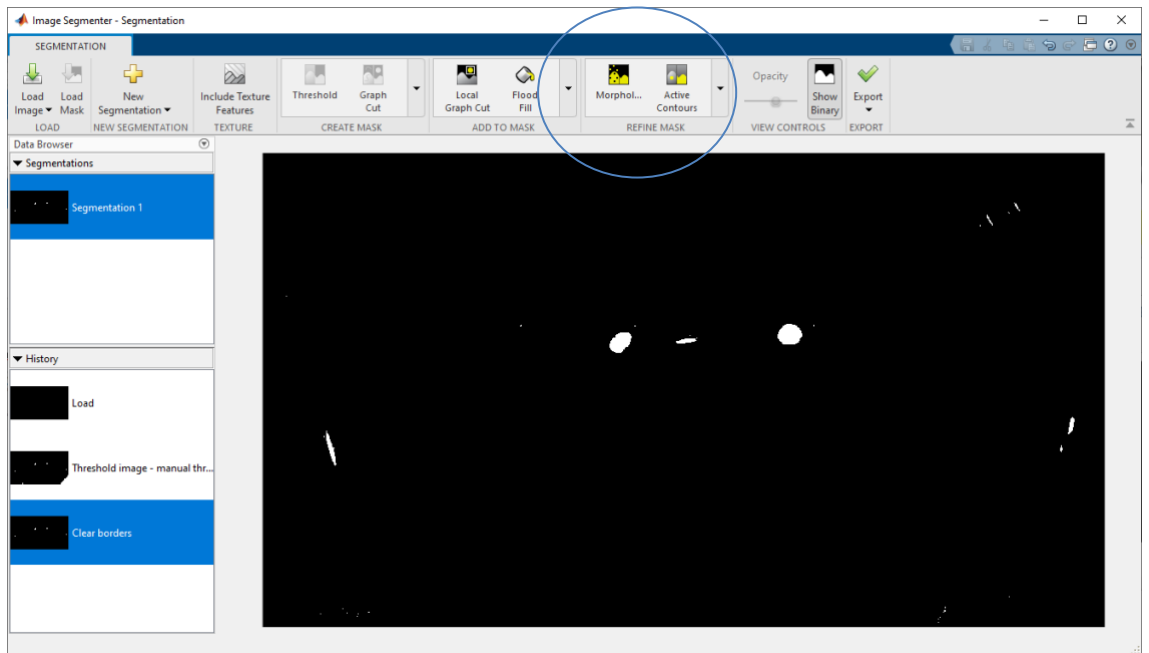


Figure 4.25: Morphology operations (binary) - Borders Clearing (the so-called conditional dilation with virtual image frame).

Open Mask morphology operation - erosion followed by dilation, this removes foreground objects smaller than the structuring element that was set, see `imopen` function as well. Radius of the disk structuring element was set onto value 4 based on the experimental setting.

This results in the following:

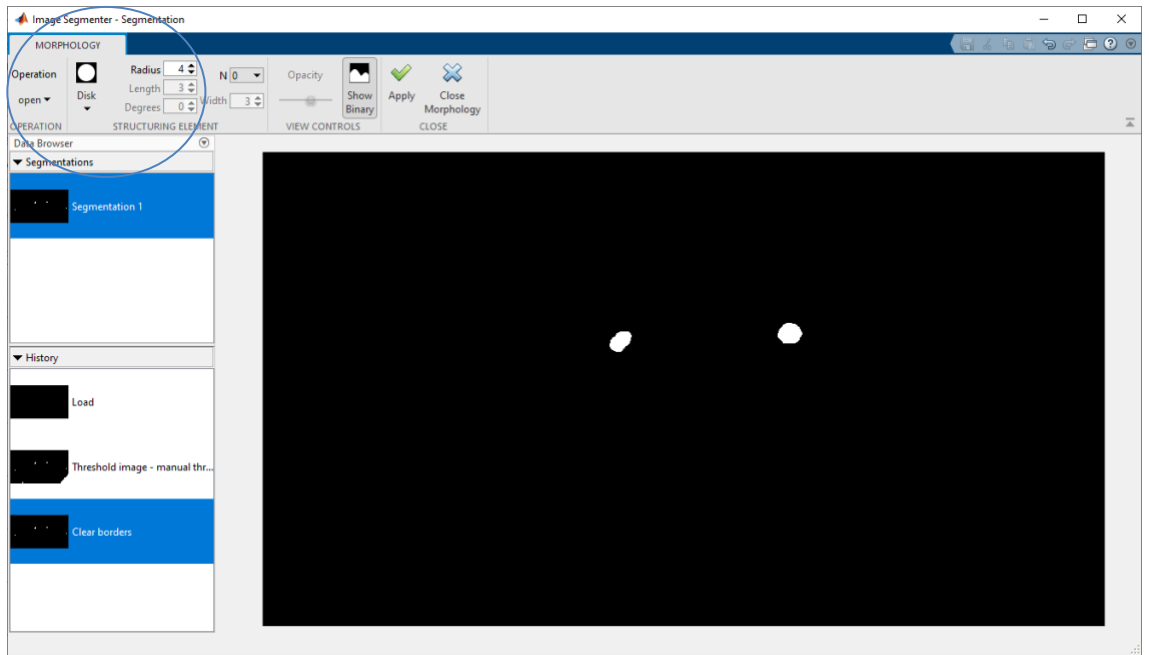


Figure 4.26: Resulting image of the mask morphology operation followed by dilation.

After that, there is a possibility of exporting from this application images or functions. Images can be copied directly into the workspace and functions are exported as m scripts. Such m scripts were used within this thesis. More importantly, it is only for better illustration and understanding. There was required to set the appropriate values for every video file and after that to optimize m scripts for the selected reasons where it was an issue to design only one m script for the automatic evaluation of trajectories.

The general flow chart seen below in Figure 4.25 shows the order of obtaining the results of the trajectory by using both semiautomatic and automatic approaches.

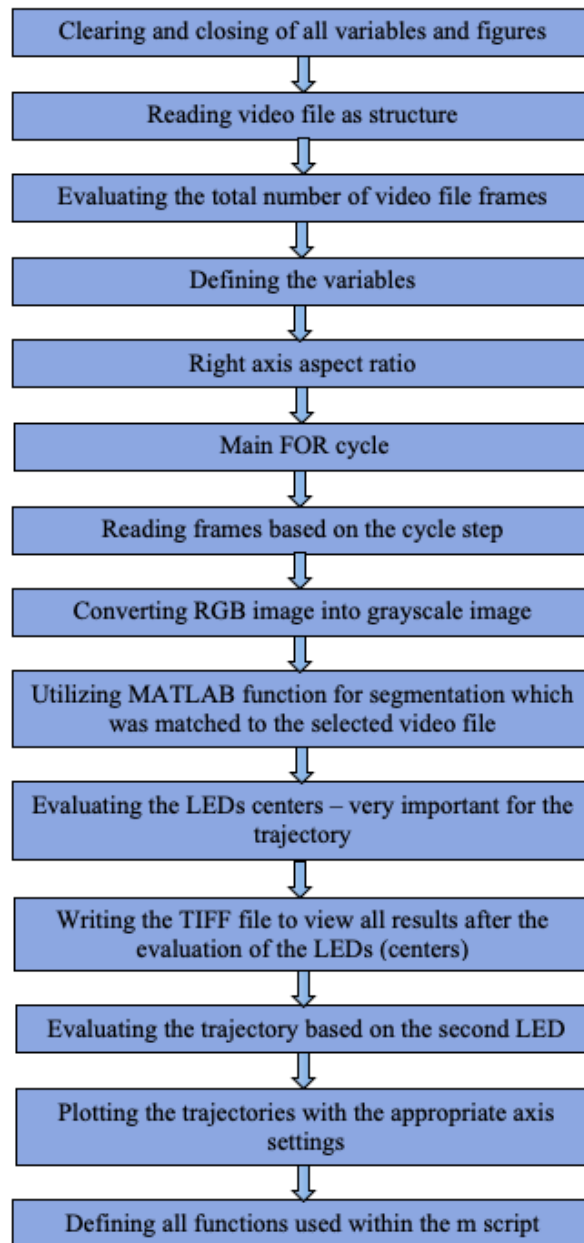


Figure 4.27: General flow chart of the m script solutions for both automatic and semiautomatic trajectory sensing.

5 Results

When the self-examine colposcope/mini camera was used for the viewing of the artificial cervix of the phantom, it was capable of viewing the cervix entirely and had optimal resolution and focus when going forward with capturing the images. The image obtained by using the self-examine colposcope/mini camera as well as the self-examine colposcope/mini camera in use can be seen in figure 5.1.



Figure 5.1: Image obtained from the phantom model using the self-examine colposcope/mini camera [photo – author].

With the Karl Kaps colposcope KP3000, the phantom cervix specifically was very easily accessed when using the speculum. The light source played a big role since it is very dark and unclear when using the colposcope with the light source off. Clinically, both the light source and metal speculum as well as the zoom, focus and distance play a huge high-powered performance in conducting such a diagnosis when viewing the cervix which can be seen in Figure 5.2.



Figure 5.2: View of phantom cervix by the colposcope using the light source [photo – author].

The colposcope with the integrated Kaps HD video camera was able to sense and record the cervix phantom. Eventually, a 2-dimensional image, found in figure 5.3, was obtained based on the optics since the in-fact purpose of colposcopy is for the evaluation of small areas and the evaluation of color which in this case is the small area around the cervical canal. The images were high in resolution and showed great details of the cervix portion of the phantom.



Figure 5.3: Image obtained of the phantom model by using the Karl Kaps colposcope KP3000 with added accessories [photo – author].

Regarding the colposcope simulator and the different methods with the flexible LEDs, these three models worked in the way a colposcope would. From the stand to the light source and even the camera integration. The only difference was visible with the difference in light flux. The results of the images captured with the different light sources can be seen in Figure 5.4 a, b, c and d.

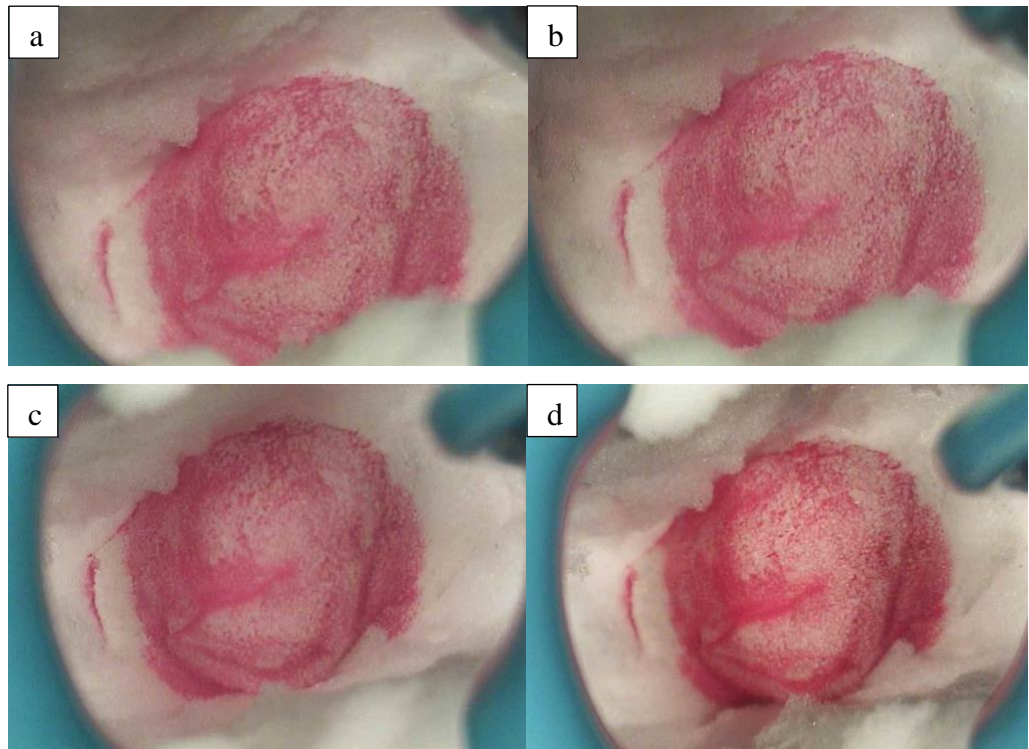


Figure 5.4: Images obtained while using the a) short flexible LED lamp, b) long flexible LED lamp, c) both flexible LED lamps and d) both flashlights from the first colposcope model [photo – author].



Figure 5.5: Panoramic stitching of the first set of images (see Figure 4.14 a).

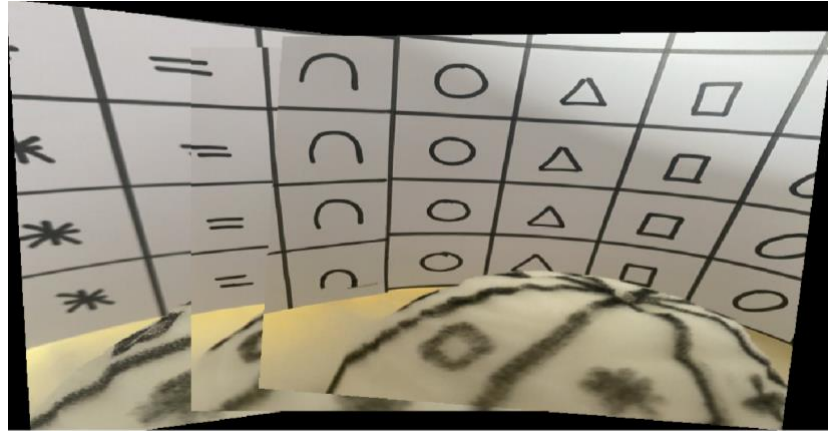


Figure 5.6: Panoramic stitching of the second set of images (see Figure 4.14 b).

The resulting images seen below in Figure 5.7 are the images obtained by the fisheye to panorama m script found in appendix B. Figure a shows the circumference of the miniature cervix phantom, Figure b shows the circumference of the cone phantom and Figure c shows the circumference of the square phantom. The difference in both shape, size and symmetry can be clearly detected between the three phantoms. This method successfully fulfilled the aim of reconstructing the whole anatomy of the cervix.

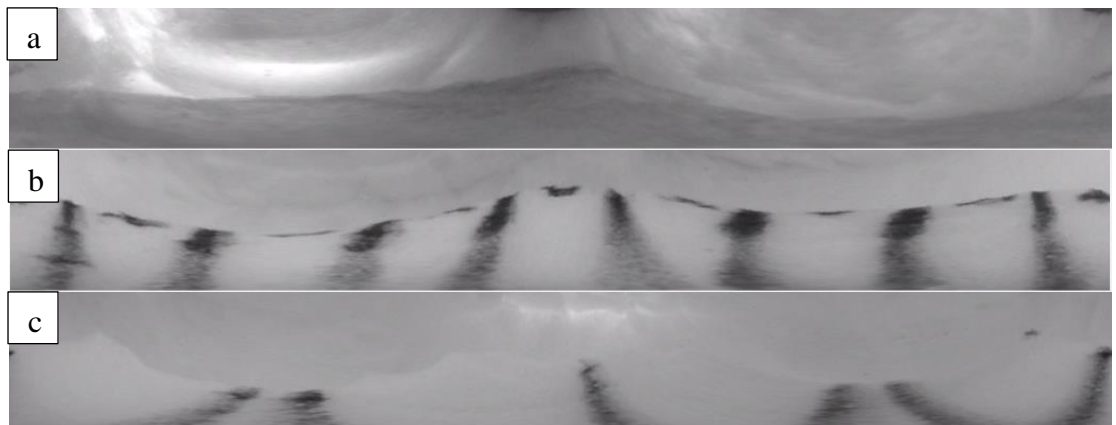


Figure 5.7: Panoramic image of a) Mini cervix phantom, b) Cone cervix phantom and c) Square cervix phantom.

Sensing the path of the trajectory of the LLETZ model was acquired with two general approaches. One uses a semiautomatic approach and the other uses an automatic approach. This read each frame of four different video recordings and then displayed plots of the different paths of the trajectory corresponding to the path of the LLETZ model across the cervix. This showed a comparison of the similarities and differences between each LED trajectory and how the LED trajectories behaved. The Figures below (Figure 5.8 till Figure 5.27] show the resulting plots of the LED trajectory paths when using the m scripts that were specifically designed to obtain these results.

Based on the results obtained, the m scripts were successful in obtaining the true path of the trajectories. After the frames were read, the trajectory was evaluated in a such

a way where the movements of the LED trajectories were in correlation with the movement of the LLETZ loop model with the integrated LEDs that was designed. All the graphs for the trajectories were designed with an X and Y axis ratio equal to 1.

All m scripts were successful in fulfilling the aim that was first set for the purpose of obtaining the trajectory.

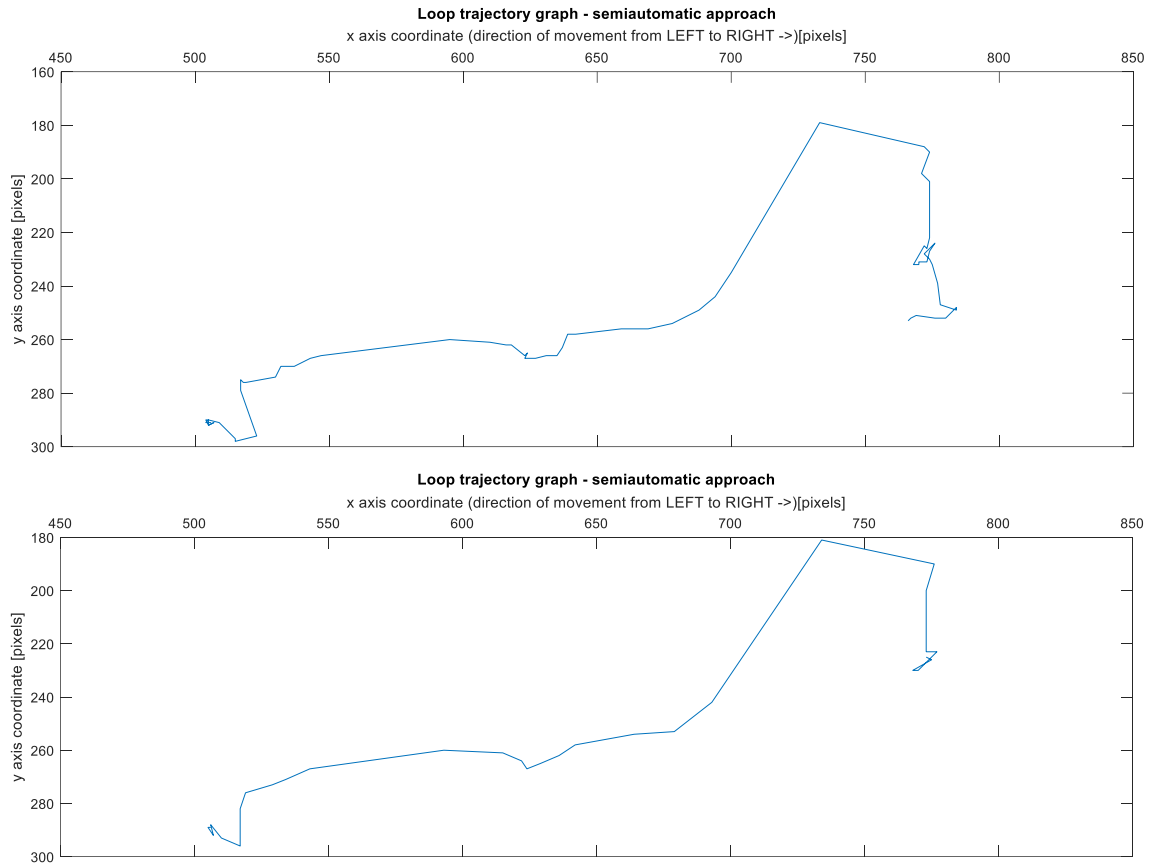


Figure 5.8: Semiautomatic trajectory sensing of the top LED from left to right direction of movement. Top figure $s=1$ (every frame was used), bottom figure $s=2$ (every second frame was used).

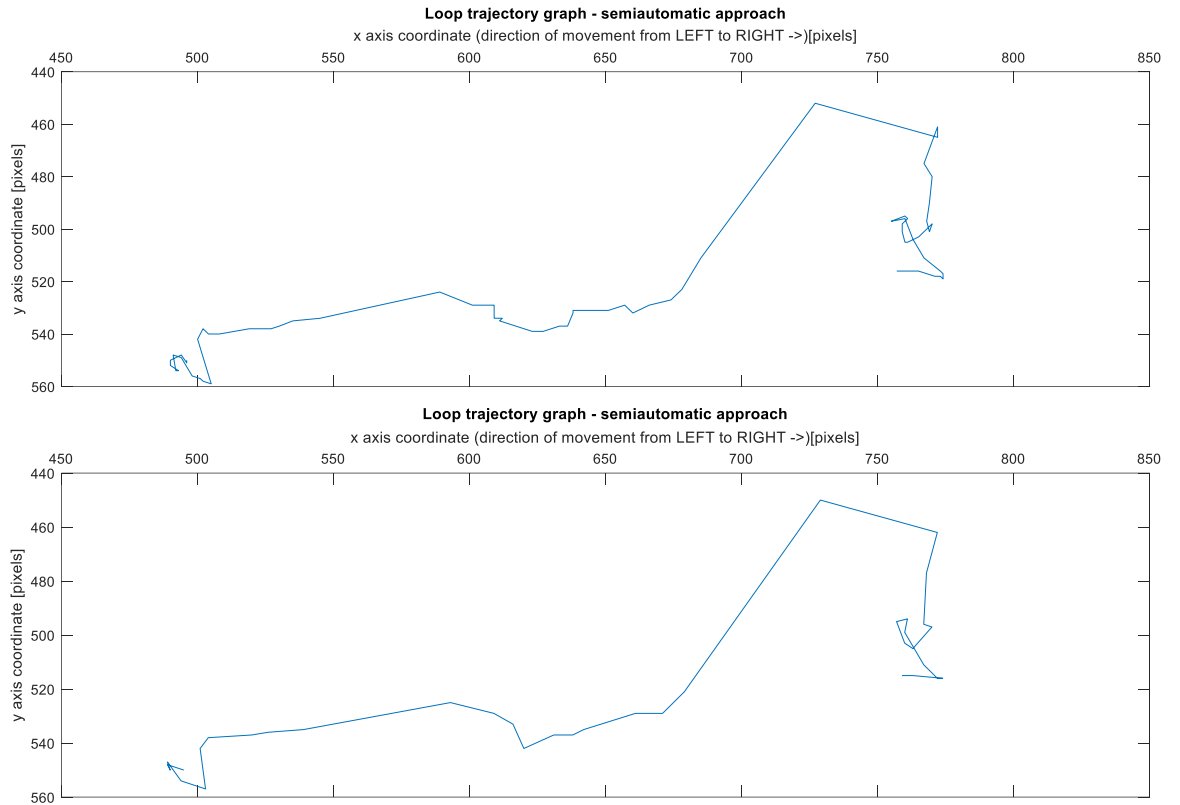


Figure 5.9: Semiautomatic trajectory sensing of the bottom LED from left to right direction of movement. Top figure $s=1$ (every frame was used), bottom figure $s=2$ (every second frame was used).

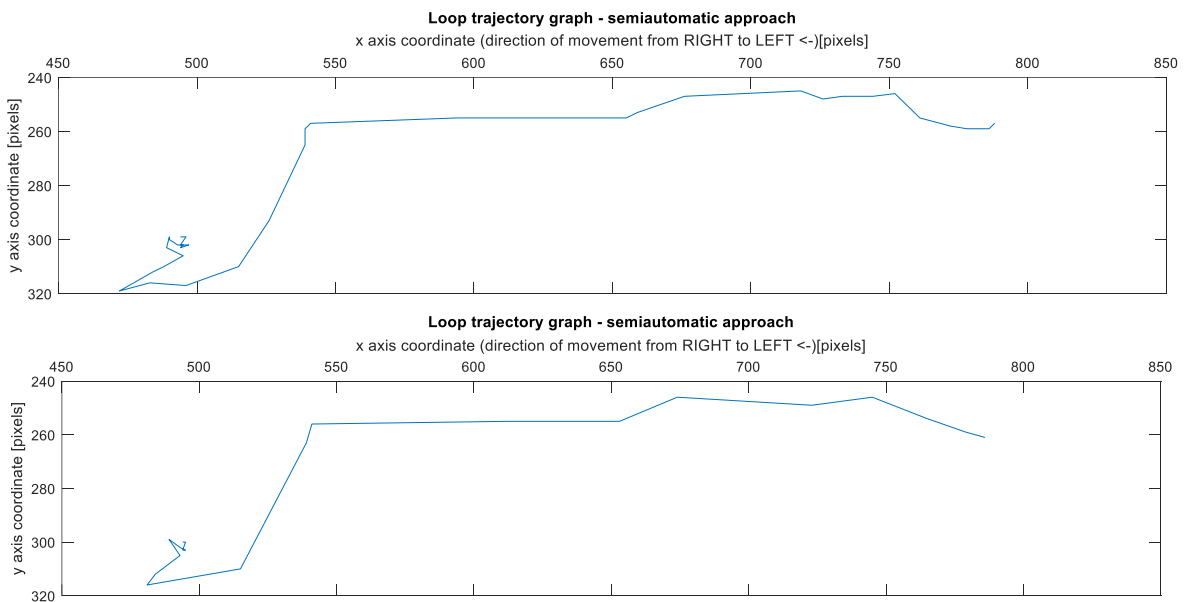


Figure 5.10: Semiautomatic trajectory sensing of the top LED from right to left direction of movement. Top figure $s=1$ (every frame was used), bottom figure $s=2$ (every second frame was used).

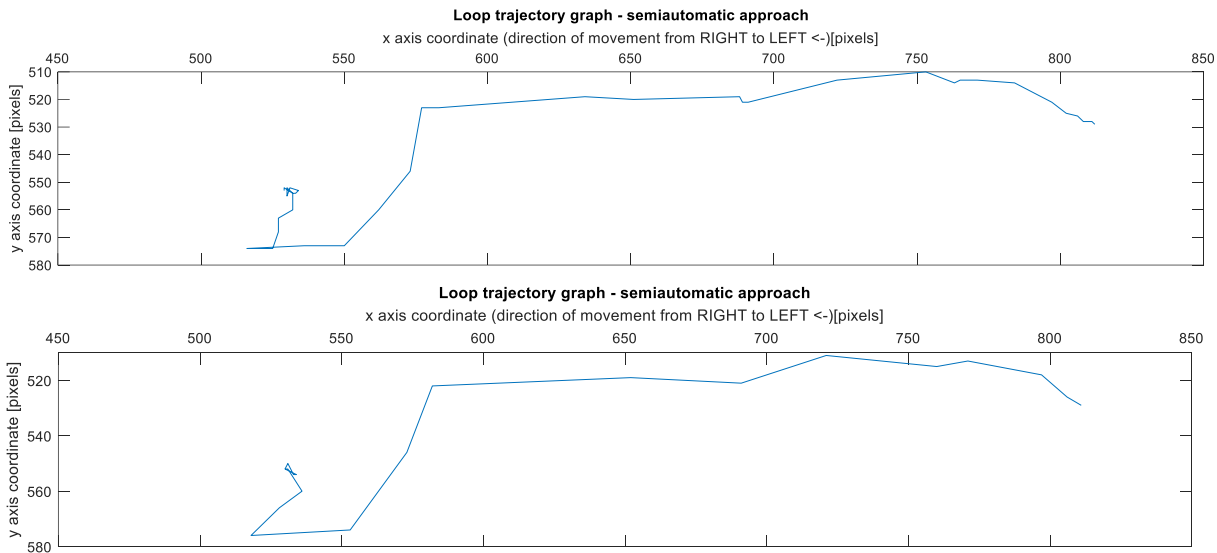


Figure 5.11: Semiautomatic trajectory sensing of the bottom LED from right to left direction of movement. Top figure $s=1$ (every frame was used), bottom figure $s=2$ (every second frame was used).

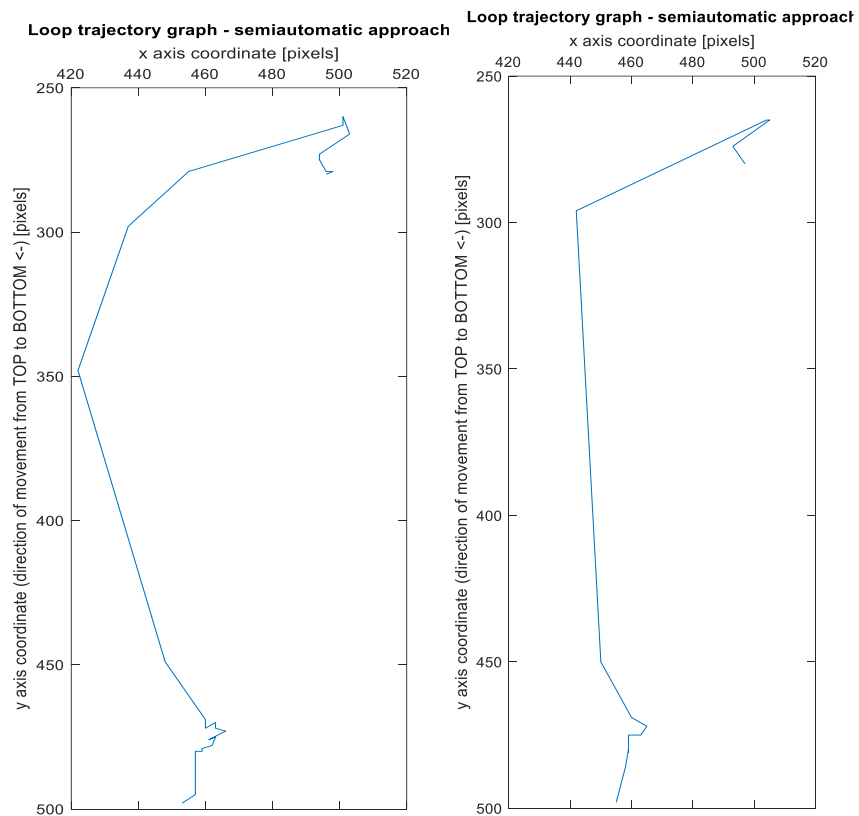


Figure 5.12: Semiautomatic trajectory sensing of the left LED from top to bottom direction of movement. Left figure $s=1$ (every frame was used), right figure $s=2$ (every second frame was used).

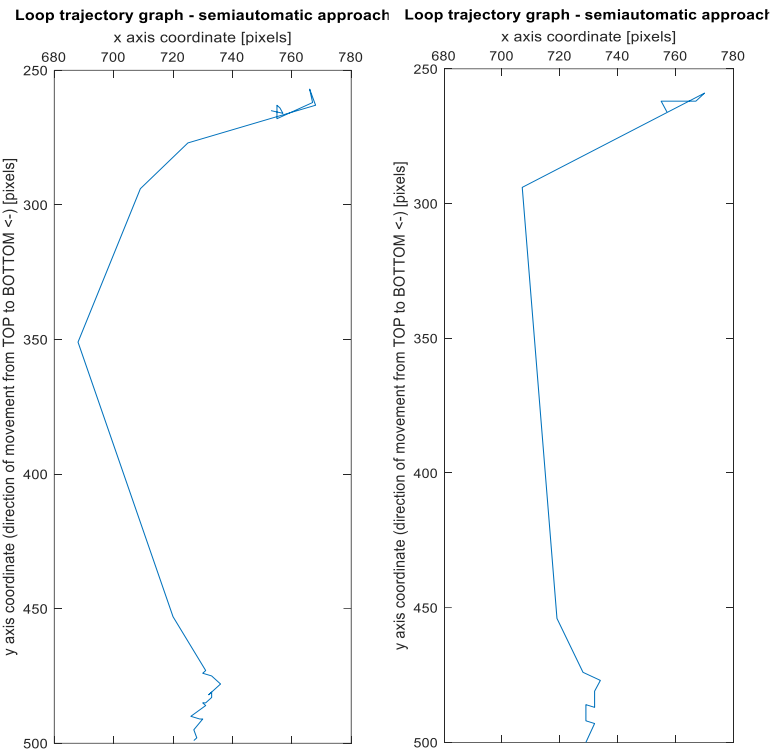


Figure 5.13: Semiautomatic trajectory sensing of the right LED from top to bottom direction of movement. Left figure $s=1$ (every frame was used), right figure $s=2$ (every second frame was used).

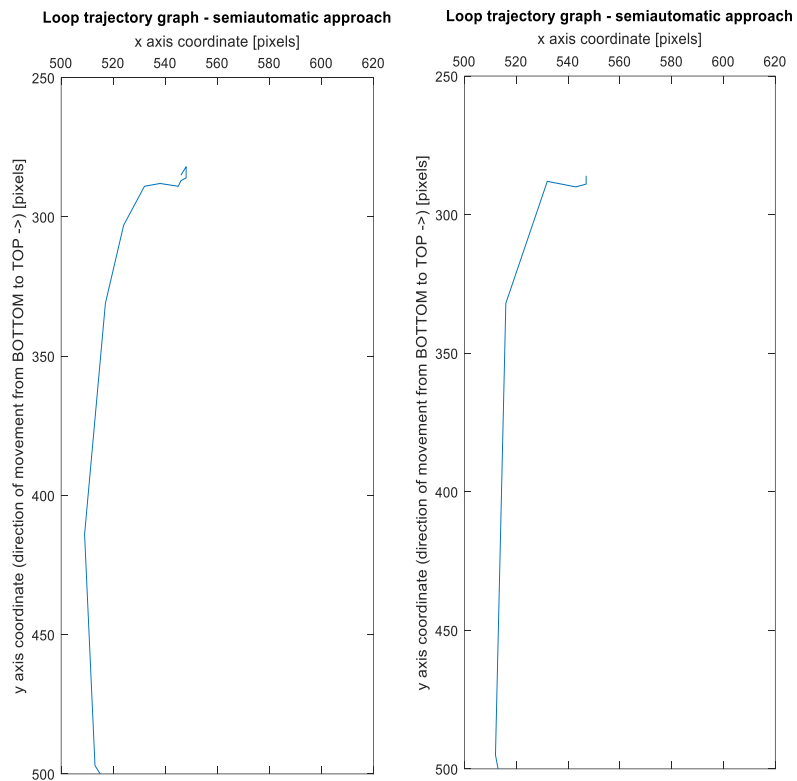


Figure 5.14: Semiautomatic trajectory sensing of the left LED from bottom to top direction of movement. Left figure $s=1$ (every frame was used), right figure $s=2$ (every second frame was used).

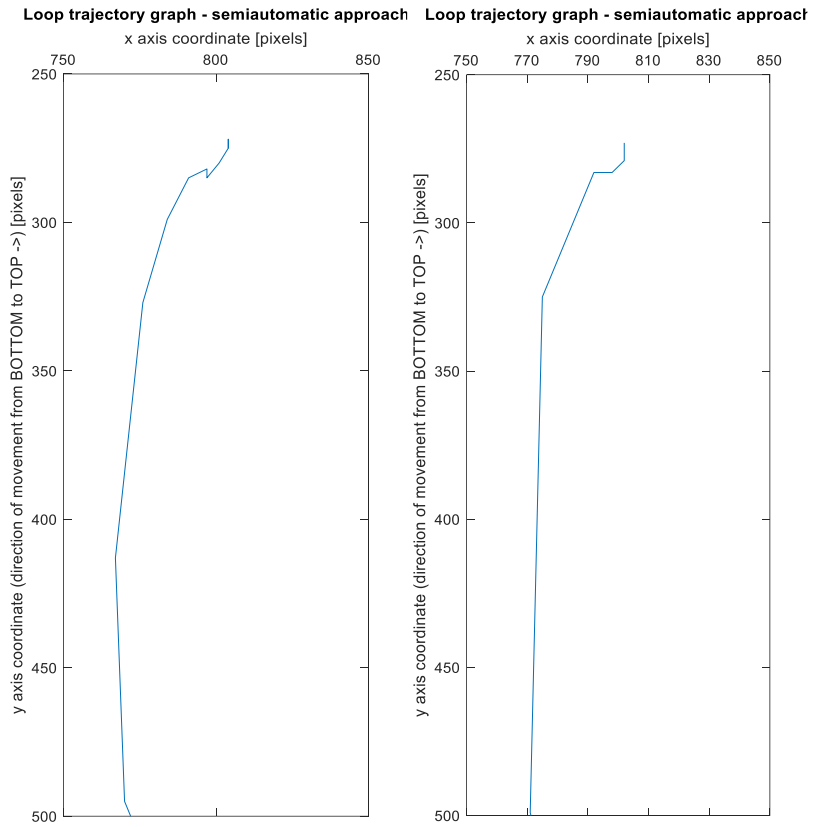


Figure 5.15: Semiautomatic trajectory sensing of the right LED from bottom to top direction of movement. Left figure $s=1$ (every frame was used), right figure $s=2$ (every second frame was used).

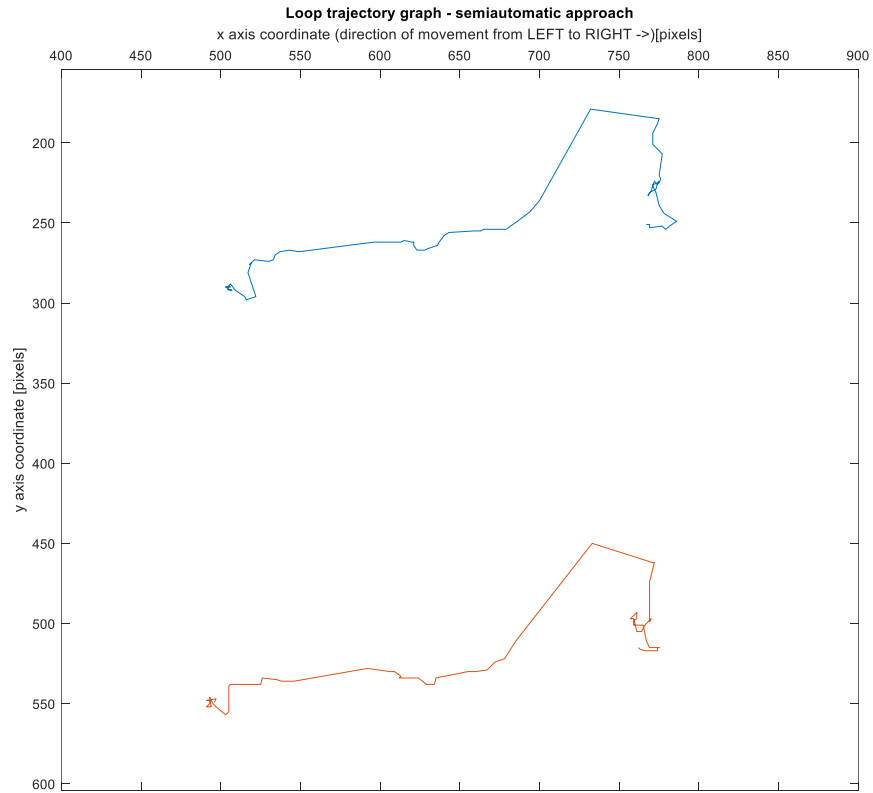


Figure 5.16: Semiautomatic trajectory sensing of both LED paths. Left to right direction of movement. Blue – top LED, red – bottom LED. $s=1$ (every frame was used).

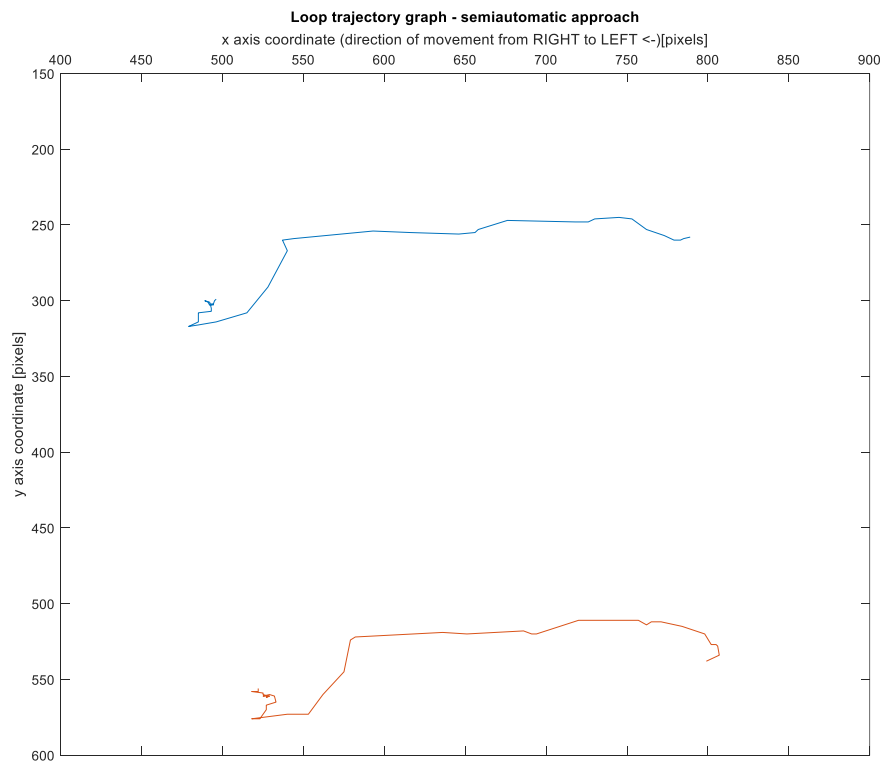


Figure 5.17: Semiautomatic trajectory sensing of both LED paths. Right to left direction of movement. Blue – top LED, red – bottom LED. $s=1$ (every frame was used).

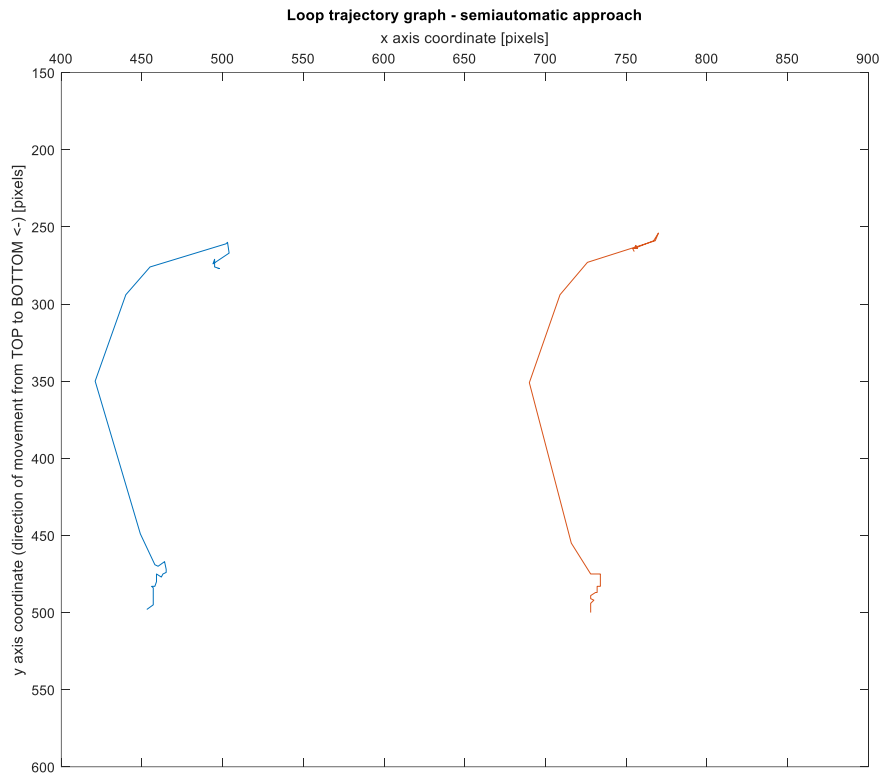


Figure 5.18: Semiautomatic trajectory sensing of both LED paths. Top to bottom direction of movement. Blue – left LED, red – right LED. $s=1$ (every frame was used).

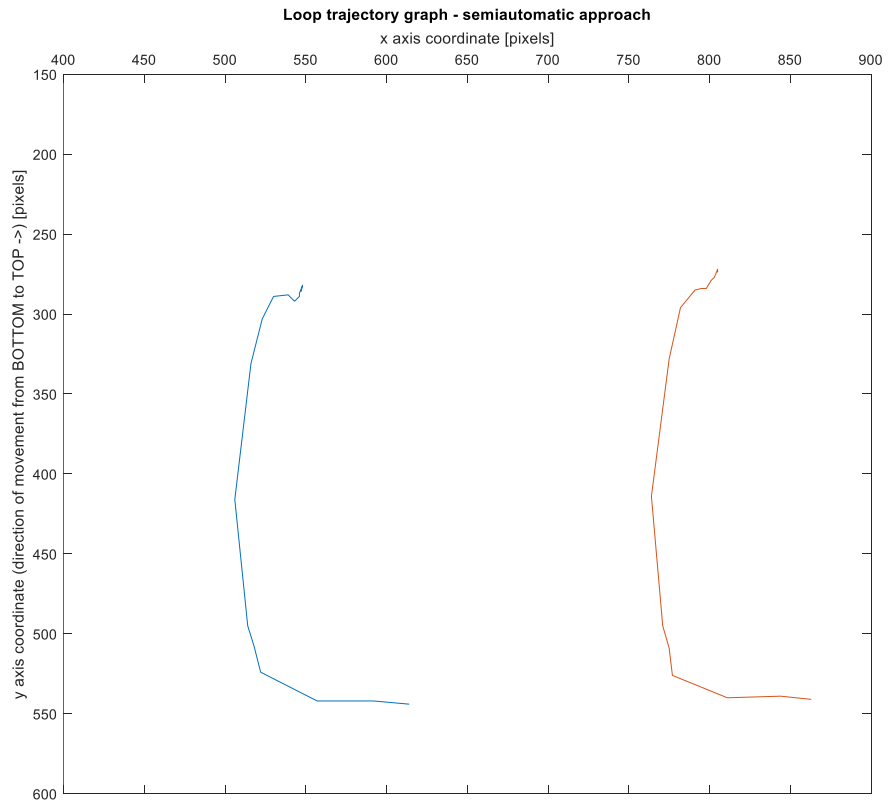


Figure 5.19: Semiautomatic trajectory sensing of both LED paths. Bottom to top direction of movement. Blue – left LED, red – right LED. $s=1$ (every frame was used).

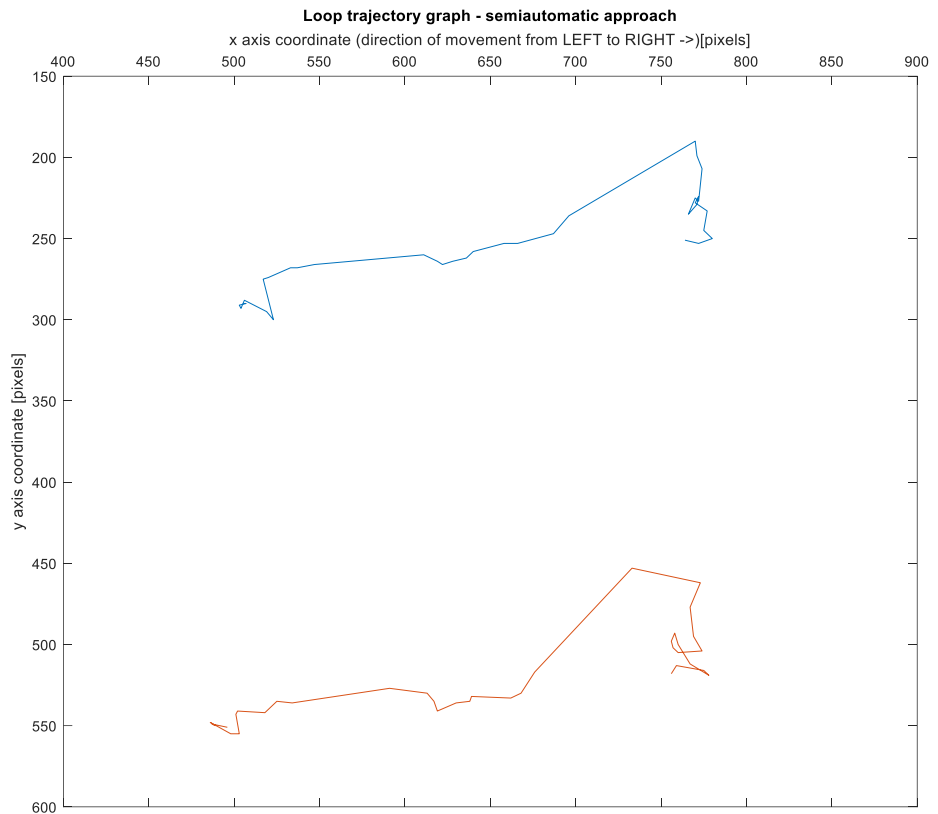


Figure 5.20: Semiautomatic ZIG ZAG trajectory sensing of both LED path. Left to right direction of movement. Blue – top LED every odd frame, red – bottom LED every even frame. $s = 1$.

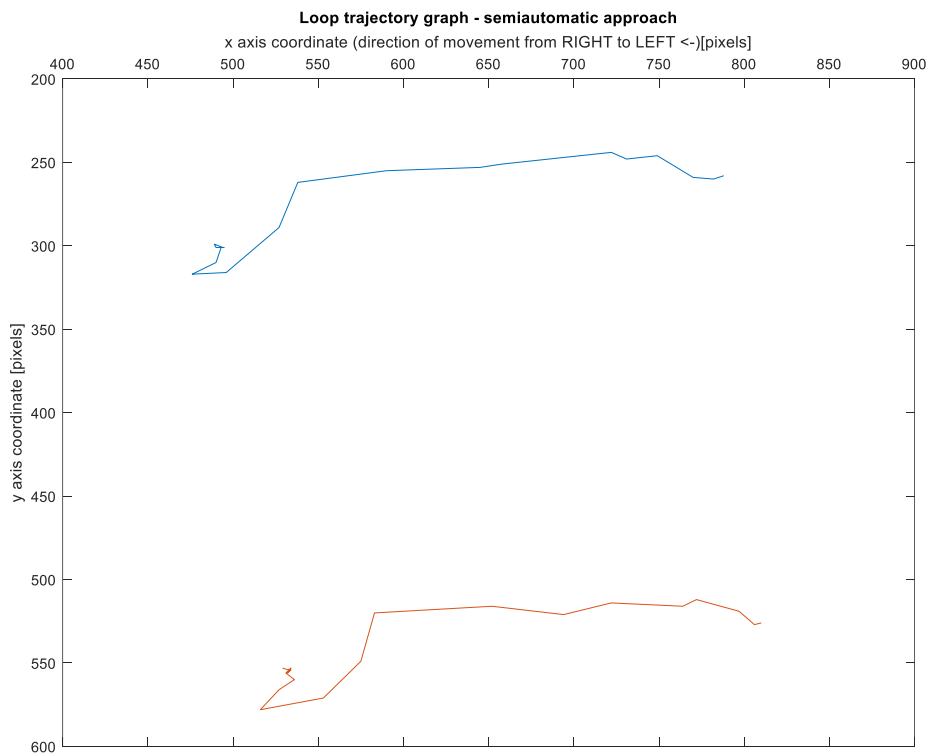


Figure 5.21: Semiautomatic ZIG ZAG trajectory sensing of both LED paths. Right to left direction of movement. Blue – top LED every odd frame, red – bottom LED every even frame. $s = 1$.

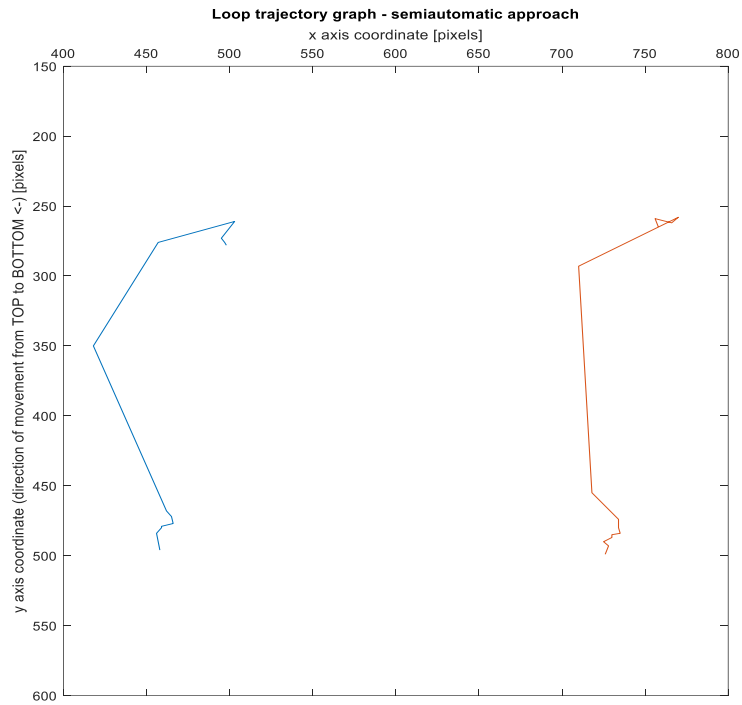


Figure 5.22: Semiautomatic ZIG ZAG trajectory sensing of both LED paths. Top to bottom direction of movement. Blue – left LED every odd frame, red – right LED every even frame. $s=1$.

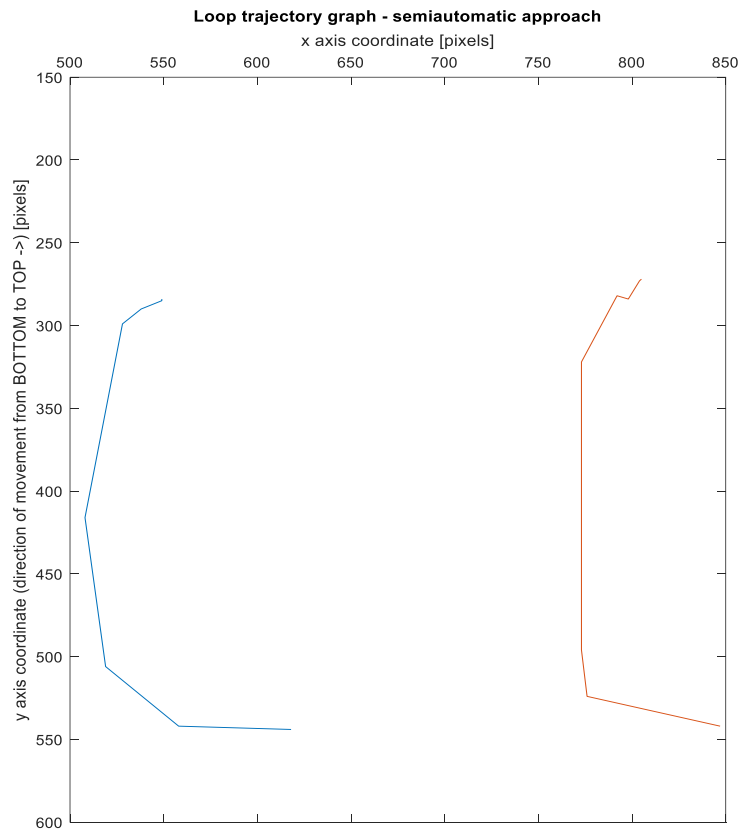


Figure 5.23: Semiautomatic ZIG ZAG trajectory sensing of both LED paths. Bottom to top direction of movement. Blue – left LED every odd frame, red – right LED every even frame. $s=1$.

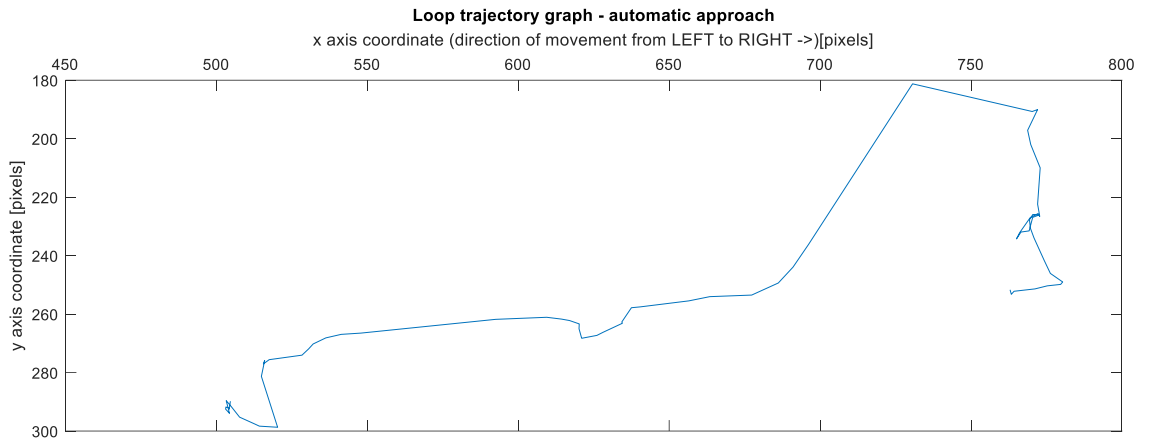


Figure 5.24: Automatic trajectory sensing of the top LED from left to right direction of movement. $s=1$ (every frame was used).

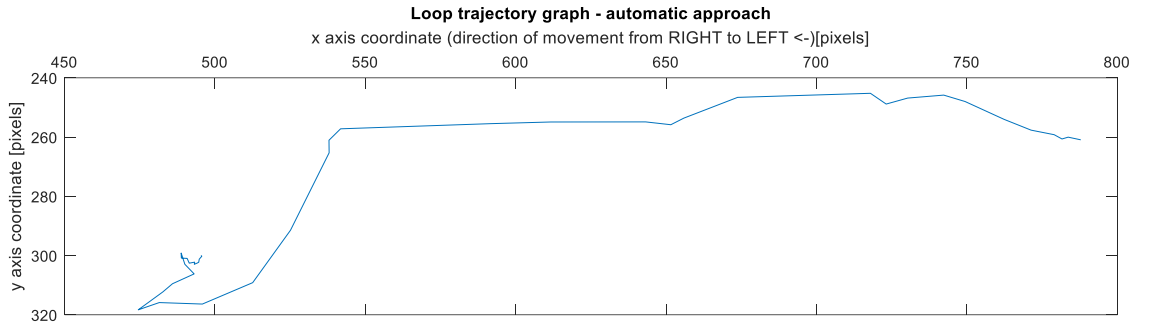


Figure 5.25: Automatic trajectory sensing of the top LED from right to left direction of movement. $s=1$ (every frame was used).

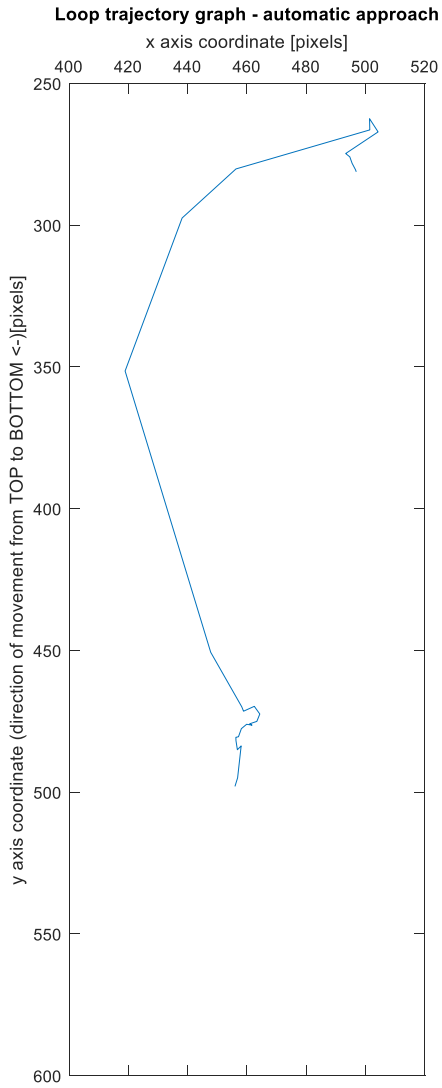


Figure 5.26: Automatic trajectory sensing of the left LED from top to bottom direction of movement. $s=1$ (every frame was used).

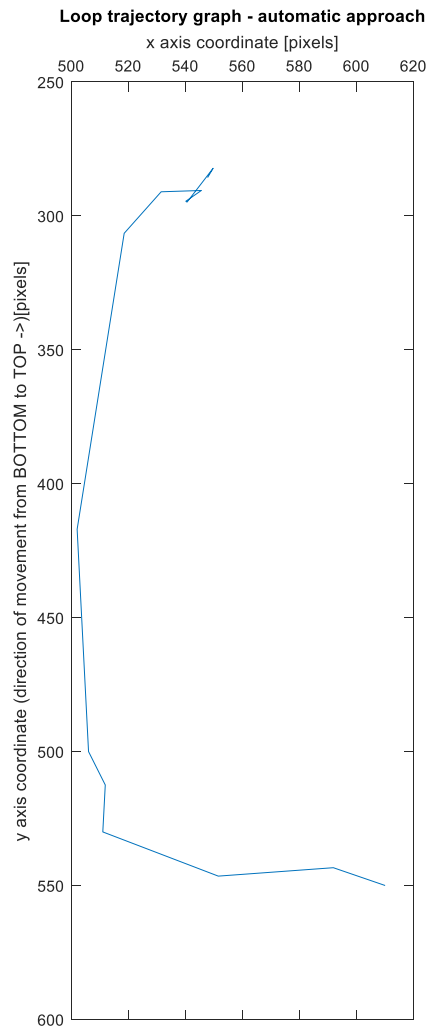


Figure 5.27: Automatic trajectory sensing of the left LED from bottom to top direction of movement. $s=1$ (every frame was used).

6 Discussion

The results demonstrated that generally the Karl Kaps colposcope KP3000 with the added accessories have better sensing and consistency than the self-examine colposcope/mini camera. Although the initial plan was to compare both colposcopes for the purpose of realizing which one works better for the cervical conization procedure, the self-examine colposcope/mini camera does not allow for the LLETZ model to play a part in the experiment since it is an invasive procedure and both the plastic speculum and colposcope need to be inserted into the phantom unlike the clinical colposcope. This is the only feedback limitation that was seen when experimenting with both colposcopes that were provided for conducting the experiment.

The results of the Karl Kaps colposcope KP3000 with the integration of the added accessories were the best option when it came to sensing and recording the conization procedure. The comparison of both devices showed that this would be the better fit.

Since the LLETZ model is an invasive device, it was able to be inserted along with the speculum and the Karl Kaps colposcope KP3000 was used for sensing. When the cervical conization procedure is done clinically, the LLETZ is used in order to cut a small cone sized piece of the cervix which gets rid of the cervical cancer. In this case, since the LLETZ is not electrically operated, it was only possible to mimic the direction the wire goes in and not get a biopsy of the phantom cervix.

The simplified colposcope simulator was constructed successfully. It worked exactly how a clinical colposcope would especially when it was compared with the Karl Kaps KP3000 colposcope. It fulfilled all the requirements of a clinical colposcope; flexibility of position, zoom, step regulation and both capturing and sensing images and video recording of the cervix model.

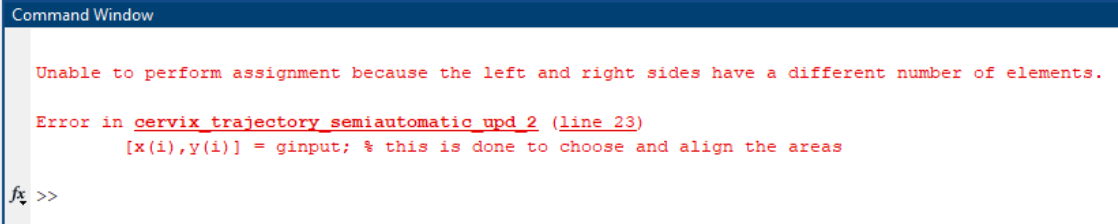
When the different lamps were used for the purpose of mimicking the light source on a clinical colposcope, there was only one difference noticed: the difference in the light flux. Both LED flexible lamps as well as the flashlights preformed as expected with delivering the light source. However, when the two flashlights were used on the initial model, there was a higher light flux and therefore a much better quality with a higher resolution was obtained for sensing and capturing images and videos. Both images in Figures 5.4 a and b look relatively similar since the same light source of LED was used but only with a difference in the parameters of the flexible lamps. Figure 5.4 c shows an even brighter light flux since both flexible lights were used at the same time. When the two flashlights were used on the initial model as seen in figure 5.4 d, there was a higher light flux and therefore a better quality in sensing and capturing images and videos.

For the reconstruction of the cervix, two methods were used and they both involved m scripts for the purpose of obtaining a single panoramic image. The first method of panoramic stitching was not the best option for the stitching of the cervix. The issue realized was the fact that it doesn't distinguish that the cervix is a cylinder and not a straight object. However, the m script had no issue realizing the background regulator and the panoramic stitching only worked on the background simulator and not on the

cervix phantom itself. Both sets of images show how well the m script worked for stitching the background regulator. Panorama stitching is not a suitable approach for the reconstruction of the anatomy of the cervix. This was the case for both sets of images used.

The second method of transforming images from the fisheye view to a panoramic one worked well and showed the whole anatomy of the cervix in one view. This method was done on all three phantoms of the cervix and was successful on all three of the phantoms.

Finally, for sensing the path of the trajectory of the LLETZ model across the cervix phantom, both x and y coordinates were secured for every frame of each of the four video recordings of different directions that the LLETZ loop travelled across the cervix phantom. The path of the trajectory was successfully obtained without any issues for all cases. However, in case of inserting the wrong coordinates within the semiautomatic approach manually, an error will occur, and the solution is to restart the m script (Figure 6.1).



```
Command Window

Unable to perform assignment because the left and right sides have a different number of elements.

Error in cervix_trajectory_semiautomatic_upd_2 (line 23)
    [x(i),y(i)] = ginput; % this is done to choose and align the areas

fx >>
```

Figure 6.1: Error within the semiautomatic m script when manually inserting the coordinates.

Regarding the trajectory sensing, evaluation and comparison, there is no significant difference for the trajectories obtained from all frames ($s=1$) or from every second frame ($s=2$). Reading every second frame ($s=2$) was useful for the purpose of speeding up the algorithm. The sensitivity of the algorithm is sufficient because of all movements were sensed and recorded. On the other hand, it is required to consider some limitations based on the number of frames; this aspect can rapidly decrease the mentioned sensitivity. In case of missing LED centers, position estimation was used based on the relevant frame and position of the corresponding LED.

7 Conclusion

To conclude this thesis, there is no denying the fact that medical practice with the use of technology is becoming more efficient, manageable, and most certainly helpful. From this point of view, there is always going to be new and improved techniques that will lead to better understandings and diagnosis within colposcopy and cervical conization. The work done within this thesis shows a different point of view for the evaluation of the cervical conization operation quality.

All the aims for the completion of this thesis were successfully optimized and fulfilled. The experiments done with the Karl kops colposcope KP3000 with the added accessories was successful when it came to the procedure cervical conization using the LLETZ model. Initially, two colposcopes were provided to prove which one of them worked best when the operational LLETZ model was used for performing the cervical conization for treating early stages of cervical cancer. The simplified colposcope simulator was successfully designed. It looked and behaved similarly to the clinical colposcope Karl kops colposcope KP3000. It provided a true observation when it came to sensing and recording the whole anatomy of the cervical models as well as the reconstruction and the evaluation of the true path of the trajectory of the LLETZ model. For reconstructing the cervical model, the panoramic stitching of captured images only worked to a certain extent where it realized the background regulator and not the cervix model itself. On the other hand, transforming the fisheye image to panorama of the three different models was successful and fulfilled. And at last, the path of the trajectory was attained fully for all different directions. Both approaches showed the true path, and the trajectory was fully obtained.

By time, the diagnosis and treatments of cervical conization will reach stages that nobody could have imagined reaching. In the future, it would be extremely useful to perform the experiments within this thesis in the real operational theaters with some additional sensing devices that will be optimal from the point of view of the dimensions, ability to sense the whole anatomy of the cervix and loop trajectory reliability.

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Appendix A: MATLAB script for panoramic image stitching [18]

```
clc;
clear all;
close all;
% Load images.

cervix = imageDatastore({' '});

% Display images to be stitched.
montage(cervix.Files)

% Read the first image from the image set.
I = readimage(cervix,1);

% Initialize features for I(1)
grayImage = im2gray(I);
points = detectSURFFeatures(grayImage);
[features, points] = extractFeatures(grayImage,points);

% Initialize all the transforms to the identity matrix. Note
that the
% projective transform is used here because the building images
are fairly
% close to the camera. Had the scene been captured from a
further distance,
% an affine transform would suffice.
numImages = numel(cervix.Files);
tforms(numImages) = projective2d(eye(3));

% Initialize variable to hold image sizes.
imageSize = zeros(numImages,2);

% Iterate over remaining image pairs
for n = 2:numImages

    % Store points and features for I(n-1).
    pointsPrevious = points;
    featuresPrevious = features;

    % Read I(n).
    I = readimage(cervix, n);

    % Convert image to grayscale.
    grayImage = im2gray(I);

    % Save image size.
    imageSize(n,:) = size(grayImage);

    % Detect and extract SURF features for I(n).
    points = detectSURFFeatures(grayImage);
    [features, points] = extractFeatures(grayImage, points);
```

```

    % Find correspondences between I(n) and I(n-1).
    indexPairs = matchFeatures(features, featuresPrevious,
'Unique', true);

    matchedPoints = points(indexPairs(:,1), :);
    matchedPointsPrev = pointsPrevious(indexPairs(:,2), :);

    % Estimate the transformation between I(n) and I(n-1).
    tforms(n) = estimateGeometricTransform2D(matchedPoints,
matchedPointsPrev, ...
        'projective', 'Confidence', 93, 'MaxNumTrials', 4000);

    % Compute T(n) * T(n-1) * ... * T(1)
    tforms(n).T = tforms(n).T * tforms(n-1).T;
end
% Compute the output limits for each transform.
for i = 1:numel(tforms)
    [xlim(i,:), ylim(i,:)] = outputLimits(tforms(i), [1
imageSize(i,2)], [1 imageSize(i,1)]);
end
avgXLim = mean(xlim, 2);
[~,idx] = sort(avgXLim);
centerIdx = floor((numel(tforms)+1)/2);
centerImageIdx = idx(centerIdx);
Tinv = invert(tforms(centerImageIdx));
for i = 1:numel(tforms)
    tforms(i).T = tforms(i).T * Tinv.T;
end
for i = 1:numel(tforms)
    [xlim(i,:), ylim(i,:)] = outputLimits(tforms(i), [1
imageSize(i,2)], [1 imageSize(i,1)]);
end

maxImageSize = max(imageSize);

% Find the minimum and maximum output limits.
xMin = min([1; xlim(:)]);
xMax = max([maxImageSize(2); xlim(:)]);

yMin = min([1; ylim(:)]);
yMax = max([maxImageSize(1); ylim(:)]);

% Width and height of panorama.
width = round(xMax - xMin);
height = round(yMax - yMin);

% Initialize the "empty" panorama.
panorama = zeros([height width 3], 'like', I);
blender = vision.AlphaBlender('Operation', 'Binary mask', ...
    'MaskSource', 'Input port');

% Create a 2-D spatial reference object defining the size of the
panorama.
xLimits = [xMin xMax];
yLimits = [yMin yMax];

```

```

panoramaView = imref2d([height width], xLimits, yLimits);

% Create the panorama.
for i = 1:numImages

    I = readimage(cervix, i);

    % Transform I into the panorama.
    warpedImage = imwarp(I, tforms(i), 'OutputView',
panoramaView);

    % Generate a binary mask.
    mask = imwarp(true(size(I,1),size(I,2)), tforms(i),
'OutputView', panoramaView);

    % Overlay the warpedImage onto the panorama.
    panorama = step(blender, panorama, warpedImage, mask);
end

figure
imshow(panorama)

```

Appendix B: MATLAB script for 360-degree panoramic image expansion [21]

```
function Expand()
Src=imread('');
Src=im2double(Src);
x_dot=1010;% The abscissa of the center point of the panoramic
image
y_dot=562;% ordinate of the center point of the panoramic image
InnerR=100;% The radius of the black circle in the middle of
the panoramic camera
OuterR=500;% Note that the selection of the outer diameter must
be inside the image
Width=2*pi*OuterR;% The width of the expanded image
Height=OuterR-InnerR;% The height of the expanded image
ImgDst=zeros(Height,Height,3);

for j=1:Height
    for i=1:Width
        Angle=GetAngle(i,j);
        Radius=GetRadius(i,j);

[x,y,TempSrc]=GetRGB(Angle,Radius,Src,InnerR,x_dot,y_dot);
        ImgDst(j,i,1)=TempSrc(1);
        ImgDst(j,i,2)=TempSrc(2);
        ImgDst(j,i,3)=TempSrc(3);
    end
end
figure(2)
imshow(Src);
[m,n]=ginput(1);close(gcf);
Radius2=Radius+InnerR;
Angle2=acos((m-x_dot)/Radius2);
ExpandW2=497*Angle2;
ExpandH2=sqrt((m-x_dot)^2 + (n-y_dot)^2 );
figure(1);
imshow(ImgDst);
% hold on;plot(ExpandW2,ExpandH2,'r*','MarkerSize',15)

function dw_Angle=GetAngle(ExpandWidth,~)
dw_Angle=ExpandWidth/497;% If the size of ExpandWidth in the
main function changes, 497 has to be changed. The criterion is 2
times the pi value of ExpandWidth/497.

function Radius=GetRadius(~,ExpandHeight)
Radius=ExpandHeight;

function
[x,y,TempSrc]=GetRGB(dw_Angle,Radius,Src,InnerR,x_dot,y_dot)
Radius=Radius+InnerR;
x=round(Radius*cos(dw_Angle)+x_dot);
```

```
y=round(Radius*sin(dw_Angle)+y_dot);  
  
if x<=0 x=1;end  
if y<=0 y=1;end  
if y>=size(Src,1) y=size(Src,1); end  
if x>=size(Src,2) x=size(Src,2); end  
  
TempSrc(1)=Src(y,x,1);  
TempSrc(2)=Src(y,x,2);  
TempSrc(3)=Src(y,x,3);
```

Appendix C: MATLAB script for semiautomatic trajectory sensing of one LED

This m-file is part of the bachelor thesis that can be cited as Ammari, M. Sensing and Processing of the Image and Video from Colposcope During the Conization Kladno, 2021. Bachelor Thesis. Czech Technical University in Prague, Faculty of Biomedical Engineering. Supervisor: doc. Ing. Jiří Hozman, Ph.D.

```
clc; % Clear the command window
clear all; % Erase all existing variables
close all; % Close all figures
% section of interactive selection of the input video file
d = dir;
fn = {d.name};
[indx,tf] = listdlg('PromptString',{'Select a file.',...
    'Only one file can be selected at a time.', ''},...
    'SelectionMode','single','ListString',fn);
v = VideoReader(string(fn(indx))); % read video file
l = v.NumFrames; % total number of frames
f = 0; %initial frame - starting
s = 1; %steps between the frames
%l = 60; % last frame, but this statement can be used only in case of
canceling of some frames at the end of video
for i= 1:l
    f=f+s;
    if f <= l
        first_frame = read(v,f); % read the first video frame
        JF = rgb2gray(first_frame); % conversion RGB image to grayscale
        image

        imshow(JF);

        [x(i),y(i)] = ginput; % this is done to choose and align the
        areas
        %         that the black lines crosses in every frame. To change from
        one
        %         frame to another and to save the values, press enter. It
        will
        %         automatically save x and y coordinated for every frame. This
        %         m-script is used only for one selected LED. For the oposite
        %         LED positions evaluation there is required to use other
        script or
        %         execution of this m-script one more again but evaluation
        will
        %         be provided for the second LED
    else
        disp('f is greater than l')
        f
        l
    end
end

switch string(fn(indx))
    case {'B_T.mp4'}
        plot(x,y);
```

```

        set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
        xlabel('x axis coordinate [pixels]');
        set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
        ylabel('y axis coordinate (direction of movement from BOTTOM
to TOP ->) [pixels]');
        ylim([250 500]);
        yticks(250:50:500);
        title ('Loop trajectory graph - semiautomatic approach');
        case {'L_R.mp4'}
            plot (x,y);
            set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
            xlim([450 850]);
            xticks(450:50:850);
            xlabel('x axis coordinate (direction of movement from LEFT to
RIGHT ->) [pixels]');
            set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
            ylabel('y axis coordinate [pixels]');
            title ('Loop trajectory graph - semiautomatic approach');
            case {'R_L.mp4'}
                plot (x,y);
                set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
                xlim([450 850]);
                xticks(450:50:850);
                xlabel('x axis coordinate (direction of movement from RIGHT to
LEFT <-) [pixels]');
                set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
                ylabel('y axis coordinate [pixels]');
                title('Loop trajectory graph - semiautomatic approach');
            case {'T_B.mp4'}
                plot (x,y);
                set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
                xlabel('x axis coordinate [pixels]');
                set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
                ylim([250 500]);
                yticks(250:50:500);
                ylabel('y axis coordinate (direction of movement from TOP to
BOTTOM <-) [pixels]');
                title('Loop trajectory graph - semiautomatic approach');
        end

h = msgbox('Operation Completed');

```

Appendix D: MATLAB script for semiautomatic trajectory sensing of both LEDs

This m-file is part of the bachelor thesis that can be cited as Ammari, M. Sensing and Processing of the Image and Video from Colposcope During the Conization Kladno, 2021. Bachelor Thesis. Czech Technical University in Prague, Faculty of Biomedical Engineering. Supervisor: doc. Ing. Jiří Hozman, Ph.D.

```
clc; % Clear the command window
clear all; % Erase all existing variables
close all; % Close all figures
% section of interactive selection of the input video file
d = dir;
fn = {d.name};
[indx,tf] = listdlg('PromptString',{'Select a file.',...
    'Only one file can be selected at a time.', ''},...
    'SelectionMode','single','ListString',fn);
v = VideoReader(string(fn(indx))); % read video file
l = v.NumFrames; % total number of frames
f = 0; %initial frame - starting
s = 1; %steps between the frames
%l = 60; % last frame, but this statement can be used only in case of
canceling of some frames at the end of video
h = msgbox('Start of the 1st part - evaluation of the first selected
LED position');
for i= 1:l
    f=f+s;
    if f <= l
        first_frame = read(v,f); % read the first video frame
        JF = rgb2gray(first_frame);% coversion RGB image to grayscale
image

        imshow(JF);

        [x(i),y(i)] = ginput; % this is done to choose and align the
areas
%         that the black lines crosses in every frame. To change from
one
%         frame to another and to save the values, press enter. It
will
%         automatically save x and y coordinated for every frame.
Within
%         the first part there are evaluated position only of one LED
and
%         at second there are evaluated positions only of the second
LED
    else
        disp('f is greater than l')
        f
        l
    end
end

end
x1=x;
y1=y;
f = 0; %initial frame - starting
s = 1; %steps between the frames
```



```

%l = 60; % last frame, but this statement can be used only in case of
canceling of some frames at the end of video
h = msgbox('Start of the 2nd part - evaluation of the second selected
LED position');
for i= 1:l
    f=f+s;
    if f <= l
        first_frame = read(v,f); % read the first video frame
        JF = rgb2gray(first_frame);% conversion RGB image to grayscale
        image

        imshow(JF);

        [x(i),y(i)] = ginput; % this is done to choose and align the
areas that the black lines crosses in every frame. To change from one
frame to another and to save the values, press enter. It will
automatically save x and y coordinated for every frame

    else
        disp('f is greater than l')
        f
        l
    end

end
x2=x;
y2=y;
switch string(fn(indx))
    case {'B_T.mp4'}
        plot(x1,y1,x2,y2);
        set(gca, 'XAxisLocation', 'top'); % placing of X axis on the
top of graph
        xlim([400 900]);
        xticks([400 450 500 550 600 650 700 750 800 850 900]);
        xlabel('x axis coordinate [pixels]')
        set(gca,'YDir','reverse') % reverse direction of Y axis
        ylabel ('y axis coordinate (direction of movement from BOTTOM
to TOP ->) [pixels]')
        ylim([150 600]);
        yticks([150 200 250 300 350 400 450 500 550 600]);
        title ('Loop trajectory graph - semiautomatic approach')
    case {'L_R.mp4'}
        plot(x1,y1,x2,y2);
        set(gca, 'XAxisLocation', 'top'); % placing of X axis on the
top of graph
        xlim([400 900]);
        xticks([400 450 500 550 600 650 700 750 800 850 900]);
        xlabel('x axis coordinate (direction of movement from LEFT to
RIGHT ->) [pixels]')
        set(gca,'YDir','reverse') % reverse direction of Y axis
        ylim([150 600]);
        yticks([150 200 250 300 350 400 450 500 550 600]);
        ylabel ('y axis coordinate [pixels]')
        title ('Loop trajectory graph - semiautomatic approach')
    case {'R_L.mp4'}
        plot(x1,y1,x2,y2);
        set(gca, 'XAxisLocation', 'top'); % placing of X axis on the
top of graph
        xlim([400 900]);
        xticks([400 450 500 550 600 650 700 750 800 850 900]);

```

```

        xlabel('x axis coordinate (direction of movement from RIGHT to
LEFT <-) [pixels]')
        set(gca, 'YDir', 'reverse') % reverse direction of Y axis
        ylim([150 600]);
        yticks([150 200 250 300 350 400 450 500 550 600]);
        ylabel ('y axis coordinate [pixels]')
        title ('Loop trajectory graph - semiautomatic approach')
    case {'T_B.mp4'}
        plot (x1,y1,x2,y2);
        set(gca, 'XAxisLocation', 'top'); % placing of X axis on the
top of graph
        xlim([400 900]);
        xticks([400 450 500 550 600 650 700 750 800 850 900]);
        xlabel('x axis coordinate [pixels]')
        set(gca, 'YDir', 'reverse') % reverse direction of Y axis
        ylim([150 600]);
        yticks([150 200 250 300 350 400 450 500 550 600]);
        ylabel ('y axis coordinate (direction of movement from TOP to
BOTTOM <-) [pixels]')
        title ('Loop trajectory graph - semiautomatic approach')
    end

h = msgbox('Operation Completed');

```

Appendix E: MATLAB script for semiautomatic trajectory sensing of both LEDs – ZIG ZAG

This m-file is part of the bachelor thesis that can be cited as Ammari, M. Sensing and Processing of the Image and Video from Colposcope During the Conization Kladno, 2021. Bachelor Thesis. Czech Technical University in Prague, Faculty of Biomedical Engineering. Supervisor: doc. Ing. Jiří Hozman, Ph.D.

```
clc; % Clear the command window
clear all; % Erase all existing variables
close all; % Close all figures
% section of interactive selection of the input video file
d = dir;
fn = {d.name};
[indx,tf] = listdlg('PromptString',{'Select a file.',...
    'Only one file can be selected at a time.',''},...
    'SelectionMode','single','ListString',fn);
v = VideoReader(string(fn(indx))); % read video file
l = v.NumFrames; % total number of frames
f = 0; %initial frame - starting
s = 1; %steps between the frames
%l = 60; % last frame, but this statement can be used only in case of
canceling of some frames at the end of video
for i= 1:l
    f=f+s;
    if f <= l
        first_frame = read(v,f); % read the first video frame
        JF = rgb2gray(first_frame);% conversion RGB image to grayscale
        image

        imshow(JF);

        [x(i),y(i)] = ginput; % this is done to choose and align the
        areas
        % that the black lines crosses in every frame. To change from one
        frame to
        % another and to save the values, press enter. It will automatically
        % save x and y coordinated for every frame. Within this case in every
        frame
        % there is selected one LED, i.e. in odd frame one LED (1st) and even
        frame the
        % second LED, it→ys the same case as for s=2 for separate evaluation
        of LEDs
        % (the so called way ZIG-ZAG)

        else
            disp('f is greater than l')
            f
            l
        end
    end
end

switch string(fn(indx))
    case {'B_T.mp4'}
        plot(x(1:2:end),y(1:2:end));hold
on;plot(x(2:2:end),y(2:2:end));hold off;
```

```

        % the first part is plot of the odd frames center LED position
(top or left), the
        % second part is plot of the even frames center LED position
(bottom or right)
        set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
        xlabel('x axis coordinate [pixels]');
        set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
        ylabel('y axis coordinate (direction of movement from BOTTOM
to TOP ->) [pixels]');
        ylim([150 600]);
        yticks(150:50:600);
        title ('Loop trajectory graph - semiautomatic approach');
        case {'L_R.mp4'}
            plot(x(1:2:end), y(1:2:end));hold
on;plot(x(2:2:end), y(2:2:end));hold off;
            % the first part is plot of the odd frames center LED position
(top or left), the
            % second part is plot of the even frames center LED position
(bottom or right)
            set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
            xlim([400 900]);
            xticks(400:50:900);
            xlabel('x axis coordinate (direction of movement from LEFT to
RIGHT ->) [pixels]');
            set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
            ylabel('y axis coordinate [pixels]');
            title ('Loop trajectory graph - semiautomatic approach');
            case {'R_L.mp4'}
                plot(x(1:2:end), y(1:2:end));hold
on;plot(x(2:2:end), y(2:2:end));hold off;
                % the first part is plot of the odd frames center LED position
(top or left), the
                % second part is plot of the even frames center LED position
(bottom or right)
                set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
                xlim([400 900]);
                xticks(400:50:900);
                xlabel('x axis coordinate (direction of movement from RIGHT to
LEFT <-) [pixels]');
                set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
                ylabel('y axis coordinate [pixels]');
                title('Loop trajectory graph - semiautomatic approach');
                case {'T_B.mp4'}
                    plot(x(1:2:end), y(1:2:end));hold
on;plot(x(2:2:end), y(2:2:end));hold off;
                    % the first part is plot of the odd frames center LED position
(top or left), the
                    % second part is plot of the even frames center LED position
(bottom or right)
                    set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top
of graph
                    xlabel('x axis coordinate [pixels]');
                    set(gca, 'YDir', 'reverse'); % reverse direction of Y axis
                    ylim([150 600]);
                    yticks(150:50:600);
                    ylabel('y axis coordinate (direction of movement from TOP to
BOTTOM <-) [pixels]');
                    title('Loop trajectory graph - semiautomatic approach');

```

```
end
h = msgbox('Operation Completed');
```

Appendix F: MATLAB script for automatic trajectory sensing of one LED

This m-file is part of the bachelor thesis that can be cited as Ammari, M. Sensing and Processing of the Image and Video from Colposcope During the Conization Kladno, 2021. Bachelor Thesis. Czech Technical University in Prague, Faculty of Biomedical Engineering. Supervisor: doc. Ing. Jiří Hozman, Ph.D.

```

clear all; % Clear the command window
clear all; % Erase all existing variables. Or clearvars if you want.
close all; % Close all figures
v = VideoReader('L_R.mp4'); % read video file
l = v.NumFrames; % total number of frames
f = 1; %initial frame - starting
s = 1; %steps between the frames
%l = 60; % last frame, this statement can be used only in case of the
% canceling of some frames at the end of video
Rmin = 10; % min. radius for function imfindcircles based on Hough
transform
Rmax = 20; % min. radius for function imfindcircles based on Hough
transform
cenxy=[1,2]; % matrix for X and Y coordinates of detected circles
centersBright=[1,2]; % primary matrix for detected circles centers
centersBright(1,1)=0;% X axis position for detected circles centers
centersBright(1,2)=0;% Y axis position for detected circles centers
delete maskedImage.tif;
daspect([1 1 1]); % stretch-to-fill disabled (no distortion)
pbaspect([1 1 1]); % stretch-to-fill disabled (no distortion)
for i= 1:l
    if f <= l
        first_frame = read(v,f); % read the first video frame
        JF = rgb2gray(first_frame); % conversion RGB image to grayscale
        image
        [BW,maskedImage] = segmentImage(JF); % function for
        segmenation
        % including morphological operations
        [centersBright, radiiBright] = imfindcircles(BW, [Rmin Rmax],
        ...
        'ObjectPolarity','bright');
        % function for finding of circles within the binarized image
        imshow(maskedImage);
        imwrite(BW,'maskedImage.tif','WriteMode','append')
        if size(centersBright) == 0 % correction of exceptions
        concerning
        % the missing the circle
            cenxy(i,1)=cenxy(i-1,1);
            cenxy(i,2)=cenxy(i-1,2);
        else
            if (i == 1) | ((i > 1) & (abs(cenxy(i-1,2)-
            centersBright(1,2)) < 100))
                % solution of the evaluation of the same circle along
                the

```

```

        % trajectory due to the second LED, i.e. second
circle, % it-ys solved by condition of max. possible change of
the % coordinate, i.e. < 100
        cenxy(i,1)=centersBright(1,1);
        cenxy(i,2)=centersBright(1,2);
    else
        [r,c]=size(centersBright);
        if r == 1 & c == 2
            cenxy(i,1)=cenxy(i-1,1);
            cenxy(i,2)=cenxy(i-1,2);
        else
            cenxy(i,1)=centersBright(2,1);
            cenxy(i,2)=centersBright(2,2);
        end
    end
end
    end
    f=f+s;
else
    disp('f is greater than l')
    f
    l
end
end

end

plot(cenxy(:,1), cenxy(:,2)) % drawing of trajectory based on the
circles
% centers movement evaluation
set(gca, 'XAxisLocation', 'top'); % placing of X axis on the top of
graph
xlim([450 800]);
xticks(450:50:800);
xlabel('x axis coordinate (direction of movement from LEFT to RIGHT -
>)[pixels]')
set(gca, 'YDir', 'reverse') % reverse direction of Y axis
ylabel ('y axis coordinate [pixels]')
title ('Loop trajectory graph - automatic approach')

h = msgbox('Operation Completed');
function [BW,maskedImage] = segmentImage(X)
%segmentImage Segment image using auto-generated code from
imageSegmenter app
% [BW,MASKEDIMAGE] = segmentImage(X) segments image X using auto-
generated
% code from the imageSegmenter app. The final segmentation is
returned in
% BW, and a masked image is returned in MASKEDIMAGE.
%-----
% Threshold image - manual threshold
BW = X > 253;

% Clear borders
BW = imclearborder(BW);

% Open mask with disk
radius = 10;
decomposition = 0;

```

```
se = strel('disk', radius, decomposition);  
BW = imopen(BW, se);  
  
% Create masked image.  
maskedImage = X;  
maskedImage(~BW) = 0;  
end
```

Appendix G: Contents of the enclosed CD

- Scan of the assignment of the topic of the diploma thesis
- Abstract in English
- Key words
- The complete diploma thesis
- M script codes
- Image and video data
- Graph plots