CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING

Department of Biomedical Technology

Sensing of the conization operation by the special kind of scanning devices

Bachelor Thesis

Study program: Biomedical and Clinical Technology

Study branch: Biomedical Technician

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

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BACHELOR'S THESIS ASSIGNMENT

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II. BACHELOR'S THESIS DETAILS

Bachelor's thesis title in English:

Sensing of the conization operation by the special kind of scanning devices

Bachelor's thesis title in Czech:

Snímání operace děložního hrdla speciálními snímacími zařízeními

Guidelines:

Design and develop simplified simulator (phantom) of the conization operational field including anatomy as well. Compare possible TV scanning devices and select the most appropriate one. Perform pilot experiments with simulator (phantom) and selected TV scanning device under the laboratory conditions. The main required output is recorded video file of the whole conization procedure with possibility to analyze operational tool trajectory.

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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DECLARATION

I hereby declare that I have completed this thesis with the topic " Sensing of the conization operation by the special kind of scanning devices " independently and have attached an exhaustive list of citations of the employed sources.

I do not have a compelling reason against the use of the thesis within the meaning of Section 60 of the Act No.121 / 2000 Coll., on copyright, rights related to copyright and amending some laws (Copyright Act).

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ABSTRACT

Title of the Thesis: **Sensing of the conization operation by the special kind of scanning devices**

Considering the growing number of women diagnosed with cervical cancer, it is estimated that cervical cancer has the fourth-highest cancer rate among women worldwide. The rapid advancement of technology has significantly impacted the field of cervical cancer research, yielding several scientific breakthroughs in the prevention of this disease.

The objective of this thesis is to record cervical conization procedures using various TV scanning devices to choose the ideal one for this procedure. Optimistically, this will in obtaining an internal view of the conization to analyse the quality of the excision from the operational tool's trajectory. To fulfil the objective part of this project it was required to create a phantom that simulates the real anatomy of the cervix and vaginal canal. The structure was created with foam and shaped with scissors. There are two main parts that resemble the cervix, one before and one after conization. Both structures have been stained with a red marker to distinguish them from other parts of the structure. An additional step was also made by creating a slit on the top side of the phantom; this method was used to experiment with a different side view. This experiment was done under laboratory conditions only and not in operation theatres.

The key finding of this pilot study is the ability to track the path of the operational tool throughout recorded video files of a cervical conization process that was recorded using small cameras. Based on the outcomes, of this experiment, the ideal cameras were found to be the intraoral camera and the dual-lens endoscope camera.

Keywords:

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List of abbreviations

HPV	The human papillomavirus
CKC	cold knife cone biopsy
LLETZ	Large Loop Excision of the Transformation Zone
CIN	Cervical intraepithelial neoplasia
SIL	squamous intraepithelial lesion
DNA	Deoxyribonucleic acid
WIFI	Wireless Fidelity
TV	Television
CCTV	closed-circuit television
LED	light emitting diode
HF	high frequency
HD	high-definition video
SD	standard definition video
SDHC	Secure Digital High Capacity
SDXC	Secure Digital Extended Capacity
LCD	Liquid Crystal Display
LEEP	Loop electrical excision procedure.
PAP-smear	cytological vaginal smear
WHO	World Health Organisation
PAP- test	Papanicolaou test
MATLAB	matrix laboratory

List of symbols

Symbol	Unit	Meaning
%	[Percentage]	Amount in each hundred
cm	[cm]	A unit of length in the metric system
mm	[Length]	A unit of length in the metric system
Atm	[Pascal]	Atmospheric pressure
°F	[Fahrenheit]	Temperature scale
°C	[Celsius]	The temperature on the Celsius scale

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1   Introduction

Due to the increasing number of women being diagnosed with cervical cancer, it has been estimated that the disease has a global incidence rate of 13.3 cases for every 100,000 women. This is the fourth-highest rate of cancer among women worldwide [1]. Especially in the developing centuries due to the lack of adequate and modern health care facilities. Although cervical cancer is one of the top causes of mortality for women globally according to the World Health Organisation WHO [1]. Nowadays, cervical cancer is categorized as a preventable disease, how may this disease be prevented? The rapid advancement of technology has had a significant impact on the field of cervical cancer research which has produced several scientific achievements, including the development of preventative human papillomavirus HPV vaccinations as well as cervical cancer screening using the human papillomavirus HPV tests [2].

For the detection of aberrant cervical cells, a cervical screening test has been frequently employed. The procedure involves collecting a small sample of tissue from the cervix's surface and sending it outside the body for additional testing. This method is used to detect any anomalies that could signify early stages of cancer as well as cancer itself [3]. When cervical cancer is present, treatment options include radiotherapy in conjunction with low-dose chemotherapy in the early stages of the disease, while chemotherapy alone is used to treat advanced cervical cancer. Another method that has recently gained popularity is cervical conization. This method is an invasive surgery used to treat cervical dysplasia or very early cervical cancer. However, the cone-shaped structure of the cervix is removed in this treatment because that is the area where cervical pre-malignancies and cancers are more likely to develop and be present [4]. This area is commonly known and referred to as the transformation zone [4]. Cervical conization is accomplished with the help of excisional methods such as cold knife cone biopsy CKC, laser, and finally the Large Loop Excision of the Transformation Zone LLETZ [5].

The goal of this thesis is to help evaluate the quality of the cervical conization procedure by analysing the operational tool trajectory that can be detected by a MATLAB script. Two different special cameras will be used to record the LLETZ trajectory. Furthermore, it is an ideal method for making a comparison of the cervix before and after the cervical conization procedure which can be further evaluated.

2 Overview of the current state of the art

2.1 Cervical cancer

2.1.1 The cervix

The cervix is a cylinder-shaped neck of tissue that connects the vagina and uterus. It is located at the lowermost portion of the uterus and is primarily composed of fibromuscular tissue. The cervix is divided into two parts, the ectocervix is the part of the cervix visible from inside the vagina during a gynecologic examination. The second part is called the external os, which is an opening in the center of the ectocervix, this allows passage between the uterus and vagina. The endocervix, also known as the endocervical canal, is a tunnel that runs through the cervix from the external os into the uterus. The transformation zone refers to the overlapping border between the endocervix and the ectocervix [6]. Almost all cases of cervical carcinoma arise from the ectocervix - or endocervical mucosa transformation zone. The anatomy of the female genital system can be seen in figure 2.1
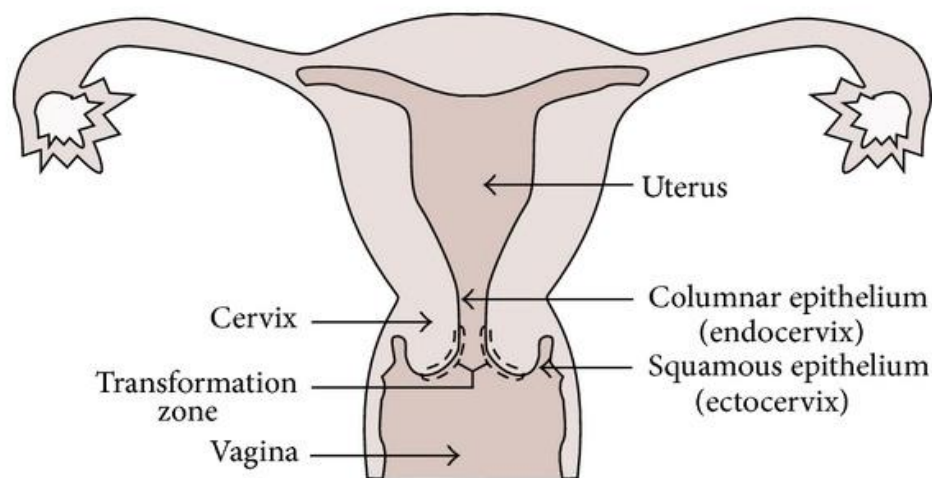
Figure 2.1 Illustrate the Female genital system [7]

Cells in the transformation zone do not transform into cancer immediately. Instead, normal cervix cells gradually develop abnormal changes that are referred to as pre-cancerous. Cervical intraepithelial neoplasia (CIN), squamous intraepithelial lesion (SIL), and dysplasia are some terms used by physicians to describe these pre-cancerous changes. Although not all pre-cancerous cells develop cancer, only some women with precancerous cells develop cancer. Precancerous cells will resolve in the majority of women without treatment. However, in some

women, pre-cancers develop into true (invasive) cancers. Treatment of cervical pre-cancers can prevent almost all cervical cancers [8].

Cervical cancer screening aims to detect pre-cancer or cancer at an early stage when it is more treatable and curable. Cervical cancer can be prevented, and many lives could be saved through regular screening. The HPV test and the Pap test are used to screen for cervical cancer. The Pap test can detect pre-cancerous changes and treat them to prevent cancer from developing. The HPV test looks for infection by high-risk types of HPV, which are more likely to cause cervix pre-cancers and cancers. Although there is no cure for HPV infection, a vaccine can help prevent it [8].

2.1.2 Primary prevention of cervical cancer

Human papillomavirus (HPV) vaccines are among the most effective prophylactic vaccines on the market, and they have set several important milestones in human vaccinology. They are the first vaccines to prevent infection by a mucosotropic sexually transmitted infectious agent without requiring specific mucosal immunity induction. They are also the first subunit vaccines to consistently induce stable serum antibody responses for over a decade.

HPV vaccines appear to induce sterilizing immunity for at least a decade after initial infection without the need for additional booster vaccination. The high efficacy discovered in prelicensure clinical trials has been confirmed by the dramatic impact and effectiveness seen in national immunization programs over the last decade. The human papillomavirus (HPV) is a DNA virus that replicates in stratified squamous epithelia [9].

Mucosal types are transmitted sexually, primarily through skin-to-skin contact. The most common sexually transmitted infection is HPV. Although most HPV infections resolve within two years and do not cause clinical disease, persistent infections with oncogenic or high-risk types can cause precancerous lesions and cancer [9]. How does it work? HPV vaccines, like other immunizations that protect against viral infection, stimulate the body to produce antibodies that bind to the virus and prevent it from infecting cells in future encounters with HPV.

Vaccination not only protects vaccinated individuals from infection by the HPV types targeted by the vaccine and possibly other types, depending on the extent of cross-protection, but it can also decrease the incidence of the vaccine-targeted HPV types in the population, consequently reducing infection in unvaccinated individuals (a phenomenon called herd protection, or herd immunity). HPV vaccination has the potential to reduce cervical cancer incidence by up to 90% globally. Furthermore, the vaccines may reduce the need for screening

and subsequent medical care, biopsies, and invasive procedures associated with abnormal cervical screening follow-up, thereby lowering health-care costs and anxieties associated with follow-up procedures. [10].

2.1.3 Treatment of precancerous lesions

Even though the HPV vaccine is extremely effective, the screening will continue to be a top priority for cervical cancer prevention. It has been one of the most important approaches to combating cervical cancer through detecting and treating cervical lesions. Several cervical screening strategies are effective in various settings. Traditional cytology (Pap smear), liquid-based cytology, and HPV testing are widely used in the healthcare system.

If pre-cancer treatment is required and eligibility criteria are met, cryotherapy or thermal ablation are strongly advised. Both treatments are equally safe and efficacious, and they can be administered in an outpatient clinic. If women are ineligible for ablative treatment or there is a suspicion of cervical cancer, they should be referred to perform colposcopy and biopsies to make the diagnosis. Excision treatment (LLETZ) is available, and in the case of cancer, an individual treatment plan is developed based on the stage of disease, the patient's medical condition, preferences, and the availability of healthcare resources. [11].

2.2 Cervical conization

Cervical conization, also known as a cone biopsy, is depicted in Figure 2.2. It is one of the most widely used therapeutic techniques in the healthcare industry, intending to remove abnormal and precancerous cells from the cervix. [12]. This procedure has numerous indications. It can be used when pap smear and biopsy results are contradictory. The treatment of cervical cancer has to be performed on the areas of premalignant lesions. Based on that, the procedure plan has to be built. the excision tools that are used nowadays during cervical conization, such as large loop excision of the transformation zone LLETZ, laser and cold knife cone biopsy CKC [13].
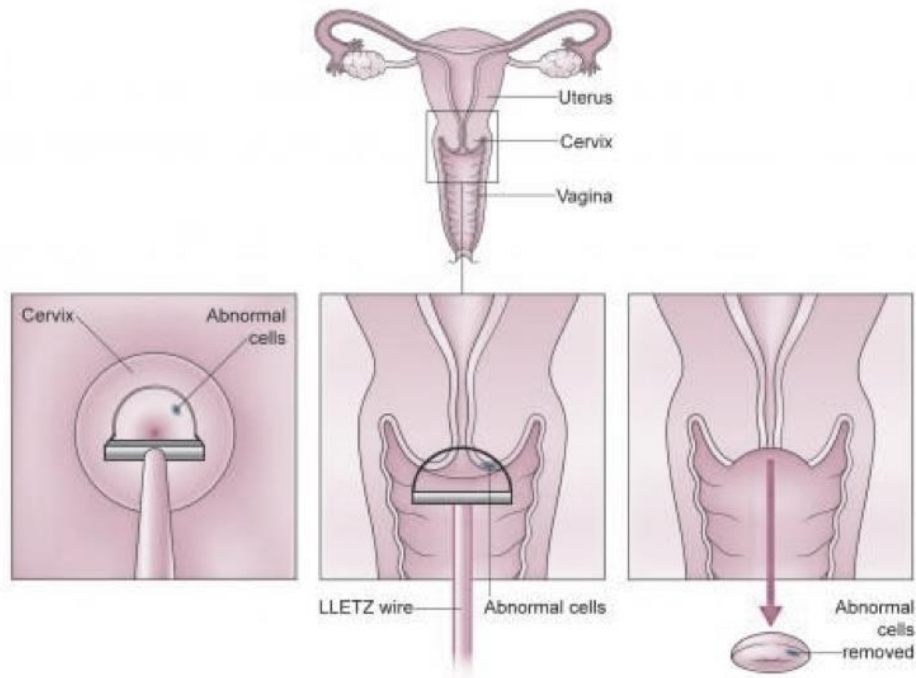
Figure 2.2 Large loop excision of the transformation zone [14]

Although cervical conization was rated as the best approach to treat cervical dysplasia, the complications are still not absent [12]. Generally, cervical conization operations are guided by a colposcope, this device has a lot of benefits, for example, it contains two eyepieces for eye positioning and the lens focus can be adjusted independently. It has a green filter which improves the quality of the image by reducing the redness in the background. Moreover, the magnification changes by performing zoom in and out of the examined object. As for all the benefits that are mentioned above, colposcopes are still unable to capture images of cone-shape cervix from all angles, but rather give a top view of the surface [15]. Therefore, in this project, one part of the aim will be to focus on the conization procedure using small cameras that assists in the recording of the cervical cone during the cervical conization.

Large loop excision of the transformation zone LLETZ has become the gold standard not only for treating all cervical premalignant lesions but as well as treating all stages of CIN (irrespective of size or location of the lesion). Due to LLETZ's low complications, such as less bleeding and a 98% success rate of treatment, it became the standard approach for all cervical premalignant treatments [16]. One advantage of LLETZ is that because the cells are removed rather than destroyed, they can be sent for additional testing to confirm the extent of the cell changes and ensure that the affected area has been completely removed [17].

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The treatment aims to remove abnormal cells from the cervix that could lead to cervical cancer while maintaining as much of a healthy cervix as possible to preserve future pregnancies. It is highly doubtful that a woman who has had LLETZ treatment for abnormal cells will have fertility problems. However, there is a slight increase in the risk of premature birth before 37 weeks after LLETZ treatment. This risk is proportional to the amount of cervical tissue removed during treatment or if the patient has had multiple LLETZ procedures [18].

2.3 Speculum

A speculum is a duck-bill-shaped device that is used by gynaecologists to examine the vagina and the cervix. The device is equipped with two pewter blades to separate the vaginal wall, which opens and closes using a screw mechanism. This invention has made a significant contribution to health care, as it aids in many procedures performed in that area which can be seen in figure 2.1.

Long before the advent of the modern speculum, health professionals continued to struggle to see the cervix and vaginal walls. As a result, they were unable to accurately diagnose medical problems occurring in those tissues. The speculum has enabled healthcare professionals to provide better gynecological diagnoses and care to women [19].

Figure 2.3 Shows two different sides of the speculum

At the end of the twentieth century and going into the twenty-first, manufacturers began developing alternative designs for the specula, such as different shapes and sizes, to provide a less uncomfortable examination Welch Allyn first introduced a large size speculum to the market in 1999, and in 2005, an extra small size was added. As of 2019, the researchers are still looking for ways to improve the plastic model. Inflatable specula the size of a tampon that inflates when inside the woman's body are among the more recent design proposals [19].

2.4 Sensing the cervix using varieties of cameras

Over the years, technology and medicine have been linked together to provide exceptional healthcare. Using a mini camera will undoubtedly improve the quality of cervical cancer detection and evaluation as it can provide an internal recording of the entire structure. Unlike colposcopes, they only provide an external recording and that results in obtaining images of the surface without the sides of the cervix. However, the proposed method requires a speculum for this kind of operation to separate the vaginal walls, concerning the diameter of the vagina. The mini camera will be inserted into the vagina until it is very close to the cervix. Then, the recording of the conization starts internally rather than externally, which is the case with the colposcope, to produce a detailed recording of the cervix from all angles. This approach has a lot of benefits, such as providing images with high resolution which achieves detailed images. It also provides an outcome of a real-time magnified image of the cervix. Thus, it will improve the quality of the cervical evaluation which helps to detect any cervical aplasia instantly in the future.

2.4.1 List of the used cameras

- Digital still camera
- WIFI TV camera where the camera lens switched with a CCTV lens
- Endoscopy rigid camera
- Professional endoscope
- Intraoral camera
- Dual-lens endoscope camera

3 Aims

3.1 General Aim

The general aim of this project is to investigate the most appropriate internal sensing device for the trajectory of the LLETZ before and after the conization. To do so, it is necessary to design a pilot experiment using a simplified simulator or phantom of the anatomical part which helps in carrying out the final evaluation of the project under laboratory conditions only.

3.2 Specific Aims

- Prepare a phantom that is close to the real anatomical part.
- Compare and select the most suitable image sensing device.
- Compare the reliability and sensitivity of the sensing device.
- Perform a full recording of the cervix before and after the cervical conization operation.
- The possibility to analyze operational tool trajectory.
- To assist physicians to evaluate the quality of the excision.

4   Methods

4.1   Used methods

To begin the experiment, all cervical sensing devices were independently prepared with appropriate sitting, as well as an external LED light for illumination purposes. The next step was to make a model that represents the real cervix made of flexible foam. Following that, a gynaecological tool known as a speculum was inserted inside the phantom to examine the cervix for the procedure. Each of the aforementioned cameras has been used and tested separately to record the cervix under the main output criterion. The primary objective of the project is to work with a small camera that can be penetrated inside the phantom. However, the cervical conization procedure was carried out using just two cameras. The steps that follow are further outlined.

4.2   Study Design

To achieve the aims of the project, it was necessary to create a phantom simulator of the cervix. The design of the phantom is relevantly simple which was created out of foam and shaped using a pair of scissors. Initially, the foam was cut into three different parts that are not equal in size. Two separate phantoms of the cervix were made, one was made to represent the cervix before the conization procedure, and the other was made to represent the cervix after the conization procedure. The vaginal canal was created using the largest piece of foam, as shown in figure 4.1 (B), a canal is made from one side throughout the structure to the other side where the speculum can be inserted, and the cervical phantoms interchanged on the opposite side that can be seen in figure 4.2 (A) and (B). The desired structure of the resultant phantom is present in figure 4.3.
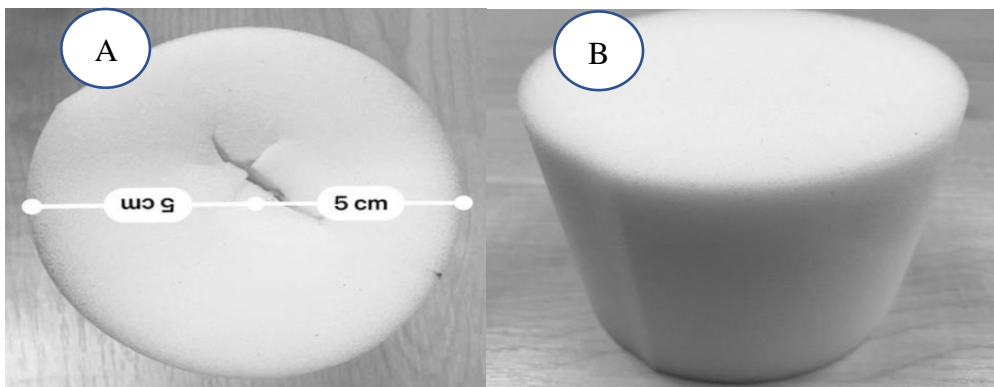
Figure 4.1 Cylindrical-shaped foam represents the phantom [photo – author].

The cervix has been stained with a red marker in both phantoms to distinguish them from other parts of the structure. Cervical staining was a critical step because the cervix must be identified visually to sense the conization trajectory process. The phantom was prepared to mimic a real cervix. As a result, the actual size of the cervix was taken into consideration, which would be 2.5cm in diameter and the length, which is 4cm. The vaginal canal was measured to be 8cm long and 4cm in diameter.
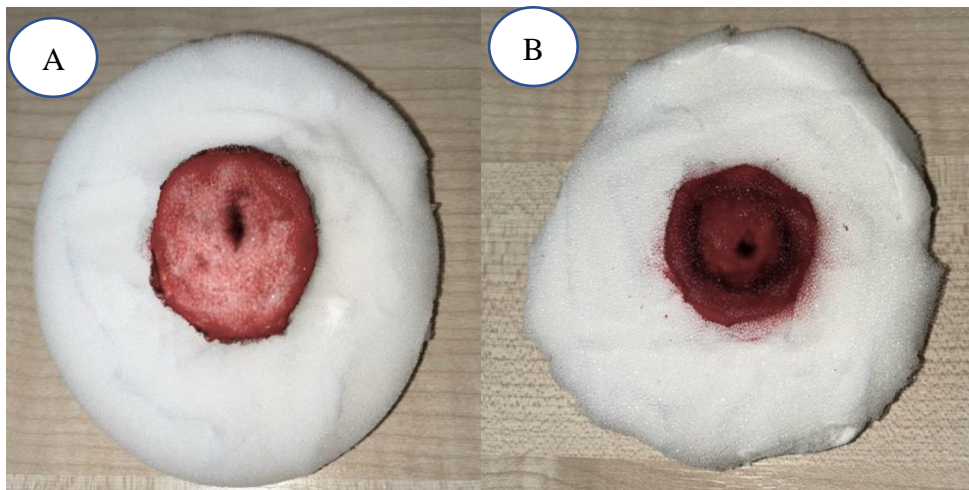
Figure 4.2 Illustration of two cervixes (A) before the conization(B) after the conization [photo-author].

Figure 4.3 Resultant phantom after assembling all the parts [photo – author].

Additionally, a small square opening was later made on the top side of the phantom cylinder. The entire structure phantom was inserted into a plastic tube/pipe. This method of experimenting is only used to experiment with a unique perspective, which would also aid in

analysing the operational tool trajectory of the entire cervical conization procedure figure 4.4 illustrates the resulting phantom and the used pipe. This method was discovered to be extremely beneficial in a variety of ways. First, the cameras were placed in the top opening, and the LLETZ was inserted through the phantom's original opening. As a result, it was simple to record the conization without the LLETZ and camera colliding. Thus, the output trajectory was not distorted. This approach was used for two of the six cameras that were used for sensing the conization operation as can be seen throughout the conduction of these experiments.

Figure 4.4 Result images after performing cut into the top side of the phantom [photo – author].

4.3   Pre-use sterilization and sanitization

Only experimental uses of small cameras are currently made, but they could be employed in clinics. For this reason, it is crucial to discuss specific sanitizing measures because the cameras will be introduced within the va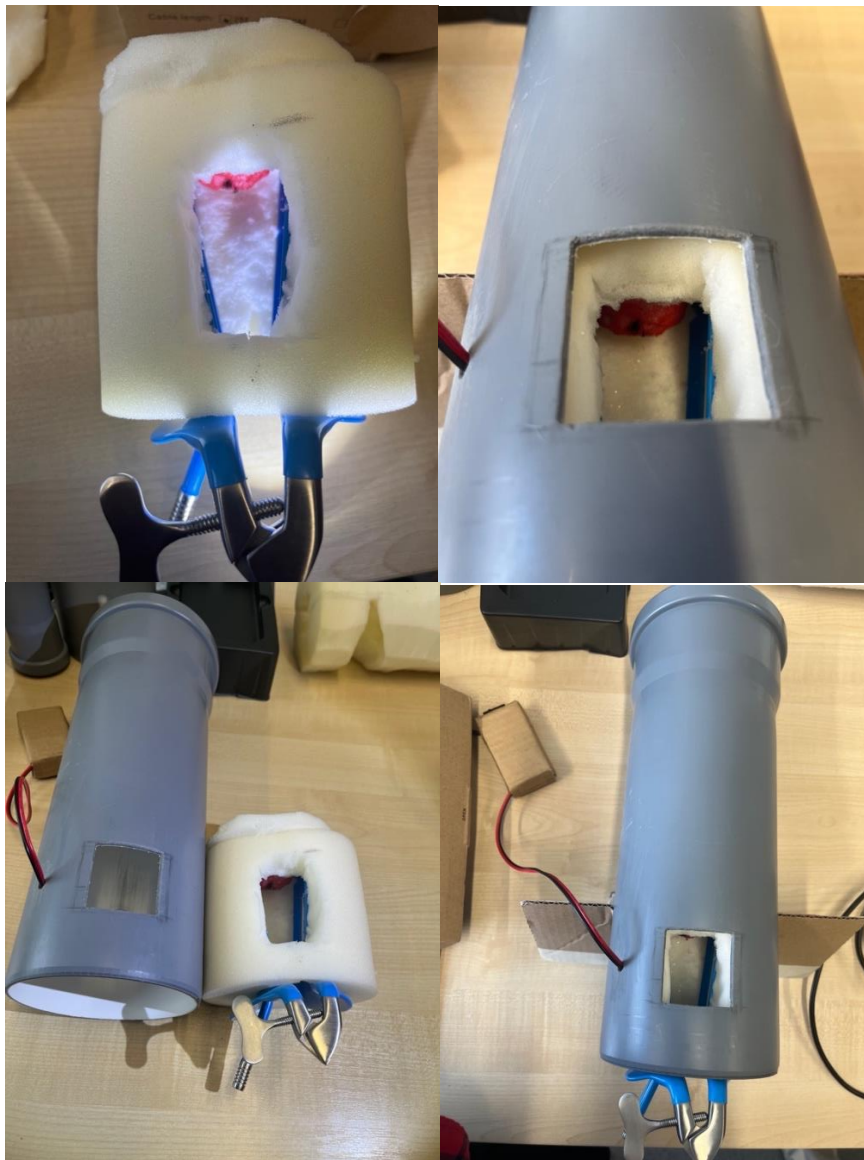gina and thus need to be properly cleaned, and sanitized after every usage, similarly to other medical equipment. The patient's health and safety are safeguarded by maintaining cleanliness. To stop the infection from spreading from one patient to another is the main reason.

Although an autoclave is the most efficient way to sterilize lab equipment, it cannot be used since the cameras cannot withstand autoclaving. Therefore, it is preferable that the cleaning be carried out manually using the following steps: The device must first be turned off, and then the battery must be removed. For hygienic purposes safety gloves are important. Use ethanol or isopropyl alcohol which is 70 % to wipe the equipment figure 4.5 shows isopropyl alcohol wipes were provided by the manufacturer. This is meant for exterior parts cleaning only. It is necessary to follow any cleaning instructions provided by the manufacturer.

Figure 4.5 Alcohol pad for sanitizing purposes [photo – author].

One of the reusable medical tools is the speculum and as a result, it is typically made of stainless steel and falls under the category of sterilization. How is it done? Before sterilization, the specula should be thoroughly cleaned of any foreign matter. It is critical to follow the manufacturer's instructions when using a steam autoclave on a tool. An autoclave is used to sterilize laboratory equipment and waste. It uses heat to kill microorganisms such as bacteria and spores. All surfaces of the sterilized specula must be exposed to direct steam. The autoclave temperature should not exceed 280°F (137°C), and the pressure should not exceed 2.2 atm. The standard cycle time of 10 minutes at 270°F (132°C) will vary depending on the model and size of the autoclave [20]

4.4 Large Loop Excision of the Transformation Zone

Large loop excision of the transformation zone (LLETZ) also known as (LEEP) loop electrosurgical excision procedure is a surgical method that removes the part of the cervix when abnormal lesions or cancer is present and is commonly used to treat cervical cell changes [21]. This was the surgical method used to conduct all the experiments concerning conization operation. The only modification made to this surgical unit is that it had been attached to a long metal rod allowing easier insertion and better access to the cervix. This can be seen in figure 4.6 below. The green part on the loop was used for detecting the trajectory of the LLETZ during the conization operation. The MATLAB script that supported sensing of the conization operation worked by sensing and following the green part, ensuring coverage throughout the whole area affected with cancerous lesions. MATLAB code is found in the appendix.

Figure 4.6 Shows the LLETZ loop excision [photo – author].

4.5   Digital still camera

Canon Legria HF R806 HD was one of the first cameras chosen. This camera has excellent features such as the ability to capture cervical images in full HD as well as intelligent image stabilization, which assisted in maintaining stability during the LLETZ conization procedure. Additional lens features include 32x optical zoom and a 57x advanced zoom [22]. The optical zooms were very useful during the LLETZ trajectory process because the recording was done noninvasively since the camera was too large to record the procedure internally, and hence, the only option was to use zooming.

As shown in Figures 4.7 and 4.8, the design of this camera is relatively simple, particularly because the portable side is easy to operate. In the following steps, it has been tested to see if it is suitable for cervical sensing operation based on all of the digital camera's features. The first step was to insert a speculum into the phantom to see the cervical cone. The next step was to illuminate the inside of the phantom, which was accomplished using the colposcope KP 3000 LED light. Finally, the cervical conization loop excision procedure was demonstrated.

Figure 4.7 shows the digital still camera from the side *[photo – author].*

Figure 4.8 shows the digital still camera frontal view *[photo – author].*

4.6 WIFI TV camera

WIFI camera was chosen for a variety of reasons, including real-time surveillance, photo capture in real-time view, and ease of access via WIFI to transfer all captured photos and videos within seconds. Furthermore, it can automatically change the image resolution based on the lighting conditions in its surroundings.

Figure 4.9 The WIFI camera before and after replacing the lens [23].

As shown in Figure 4.9, an additional plan was devised for this camera, in which the original lens was replaced with a 13 cm camera CCTV lens unit. This lens has a 210 ° ultra-wide viewing lens, which would be extremely useful during the operation.

The experiment was prepared using the same phantom and approach as described above. The phantom was placed at a height of 10 cm, with external lighting provided by colposcope KP 3000 LED lights. Due to the sensitivity of the exposure lens wire, the camera had to be held by hand to avoid any damage to the lens wire that was connected to the camera during the operation time [23].

4.7 Semi-rigid endoscope camera

A semi-rigid endoscope camera was used to achieve the project's goal of recording the cervix from the inside. Unlike most medical sensing devices, endoscopes are inserted directly into the organ to be examined. The semi-rigid endoscope camera achieved the part of the phantom's internal sensing with the help of its small size and sturdy tube, which allows the camera to be adjusted from the outside. The endoscope has a detachable screen that helps the sensing process to be monitored and displays an optimal view of the cervix on the screen, as shown in figure 4.10.

Figure 4.10 Semi-rigid endoscope with the monitor and the memory card *[photo – author]*.
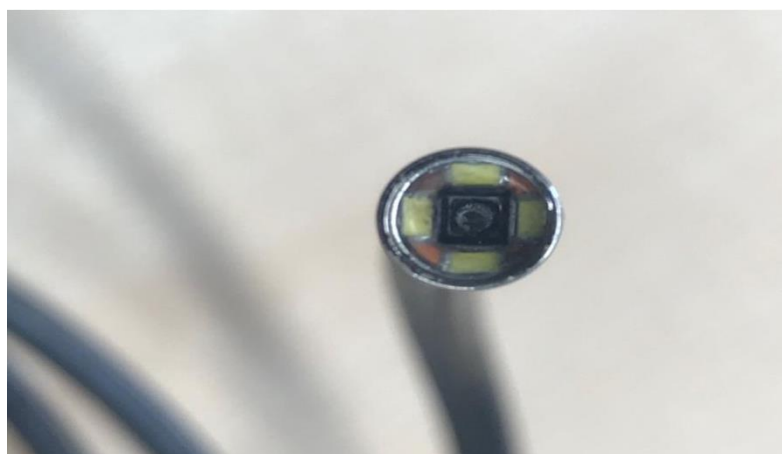

Figure 4.11 Camera of the semi-rigid endoscope *[photo – author]*.

The semi-rigid tube has a small diameter of 5.5 mm and a length of 3 meters, allowing the distal camera at its tip to easily explore the enclosed places inside the body. The camera

head is equipped with four LED lights as shown in figure 4.11, enabling it to record in the darkest of environments.

This camera was used in this experiment because of its simple and semi-flexible design, as well as because it is lightweight. The phantom was first placed in the proper position, and the speculum assisted in opening the interior walls of the structure to view the cervix. The camera was then placed inside to record. Although the brightness of the LEDs was not adjustable, the illumination was convenient [24].

4.8   Professional endoscope

The endoscope is composed of a control head and a flexible shaft with an adjustable tip. An 'umbilical' cord connects the head to a light source, through which other tubes transmit air, water, and suction, among other things. The suction channel allows diagnostic and therapeutic tools (such as biopsy forceps) to pass through. A simplified schematic is shown in Figure 4.12.
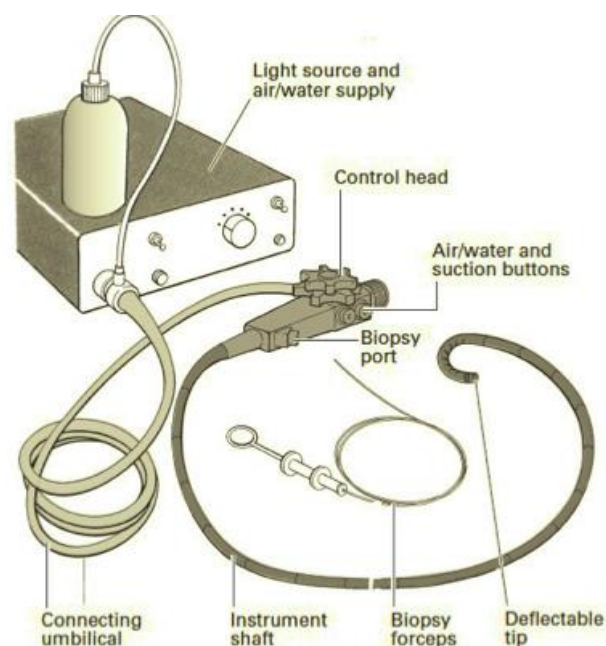
figure 4. 12 Shows labelled parts of the professional endoscope [25]

Because fibreoptic bundles are extremely flexible, an image can be transmitted even when the endoscope is tied in a knot. Most modern instruments have a fixed distal lens that focuses the image onto the bundle, and a pin-hole aperture provides a depth of focus of 10-15cm down to about 3mm. The image is reconstructed at the top of the bundle then it is transmitted to the eye via a focusing lens that can be adjusted to compensate for individual

refraction differences which can both be seen in figure 4.13 [25]. This was the first camera that was experimented with using the slit on the top side of the phantom.

Figure 4.13 Total internal reflection of light down a glass fiber and fiber bundle showing the packing fraction between fibres [25].
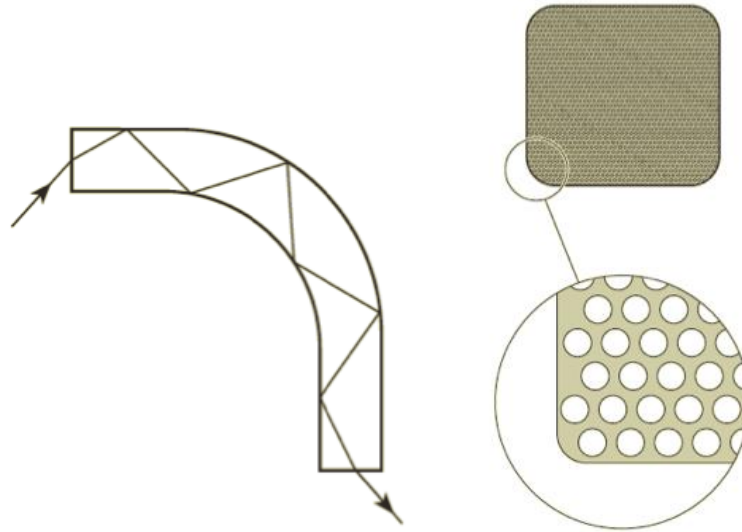
4.9   Dental Camera

An intraoral camera, also known as a dental camera, has a small lens on its tip with a wide-angle view. It has powerful magnifying properties as well as the ability to select from three different three zoom levels. The camera has eight bright LED lights distributed around the lens can be shown in figure 4.14 [35]. As a result, additional lighting was not required. In this part of the experiment, an iPhone 13 was used; it was wirelessly connected to the camera and served as a monitor throughout the recording, whilst also transmitting all the videos instantaneously because it was automatically saved to the device's media. The recorded videos were later used for analysing the trajectory of the LLETZ.

The camera used the same methodology as a professional endoscope, with the camera placed into the slit of the phantom and the recording of the cervix performed from the slit as well as from the vaginal orifice. This was the second camera that was tested using the slit on the phantom's top side [26].
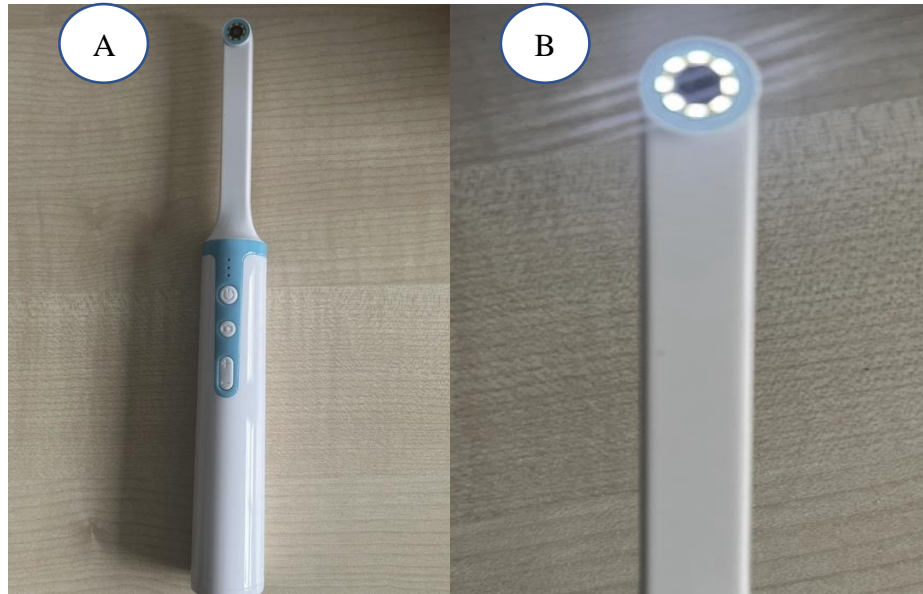
Figure 4.14 Dental camera and the close picture of the lens LED lights on [photo – author].

4.10 Dual-lens endoscope camera

Operating with a 4.3-inch screen and 8 LED lights, this dual-lens endoscope camera works closely with the same principle of the clinical endoscope. Two wide-angle lenses can be found on the tip on different sides which can be shown in figure 4.15 (A) this feature allows different angle sensing. It also displays the images and videos on its screen from the dual cameras at the same time. The important thing is that brightness levels can be adjustable up to three levels providing enough light inside a dark environment. This dual-lens endoscope has a 1920x1080p resolution and a focal length starting from 5cm up to 500cm.

Similarly, as with the rest of the cameras, the dual-lens endoscope camera has experimented with a way in which it was positioned in front of the phantom. With this, however, a second approach was considered, where first the cervix was recorded in normal operational theatre conditions and then from the different openings on the surface of the phantom to obtain different recordings from different angles. This was the third and last camera that was experimented with using the slit on the top side of the phantom [27].
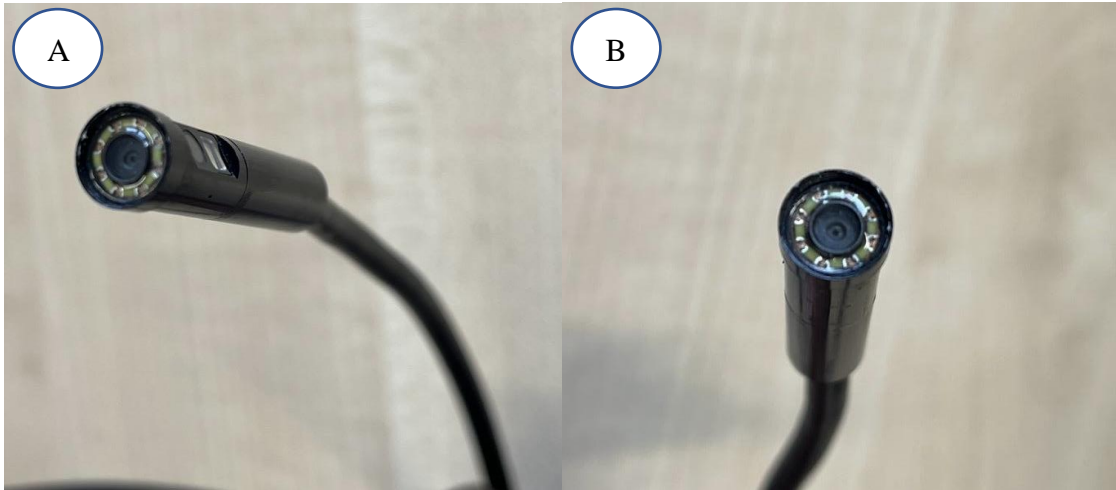
Figure 4.15 Close photo of both lenses at the tip of the endoscope [photo – author].

Figure 4.16 Screen of the dual-lens endoscope [photo – author].

4.11 The block scheme of the MATLAB script

close all, clear all, clc. used to clear the workspace and command widow from previous opened figures

Add the video to the current folder

Read the video file in MATLAB and play the video file

Create a histogram-based tracker to track the green part using syntax (vision. HistogramBasedTracker)

Initialize tracker using getLoc_function creates the bounding box to select the green part position= [x y width height] the rectangle is created using these points when manually selected

Main while loop used

Retrieve the first frame that contains the object of interest, then select it by creating rectangle around that will appear after running the code. for example, the green part of the LLETZ

The bounding box saves the pixels of this area. And search for these pixels in all the frames of the video using a while loop

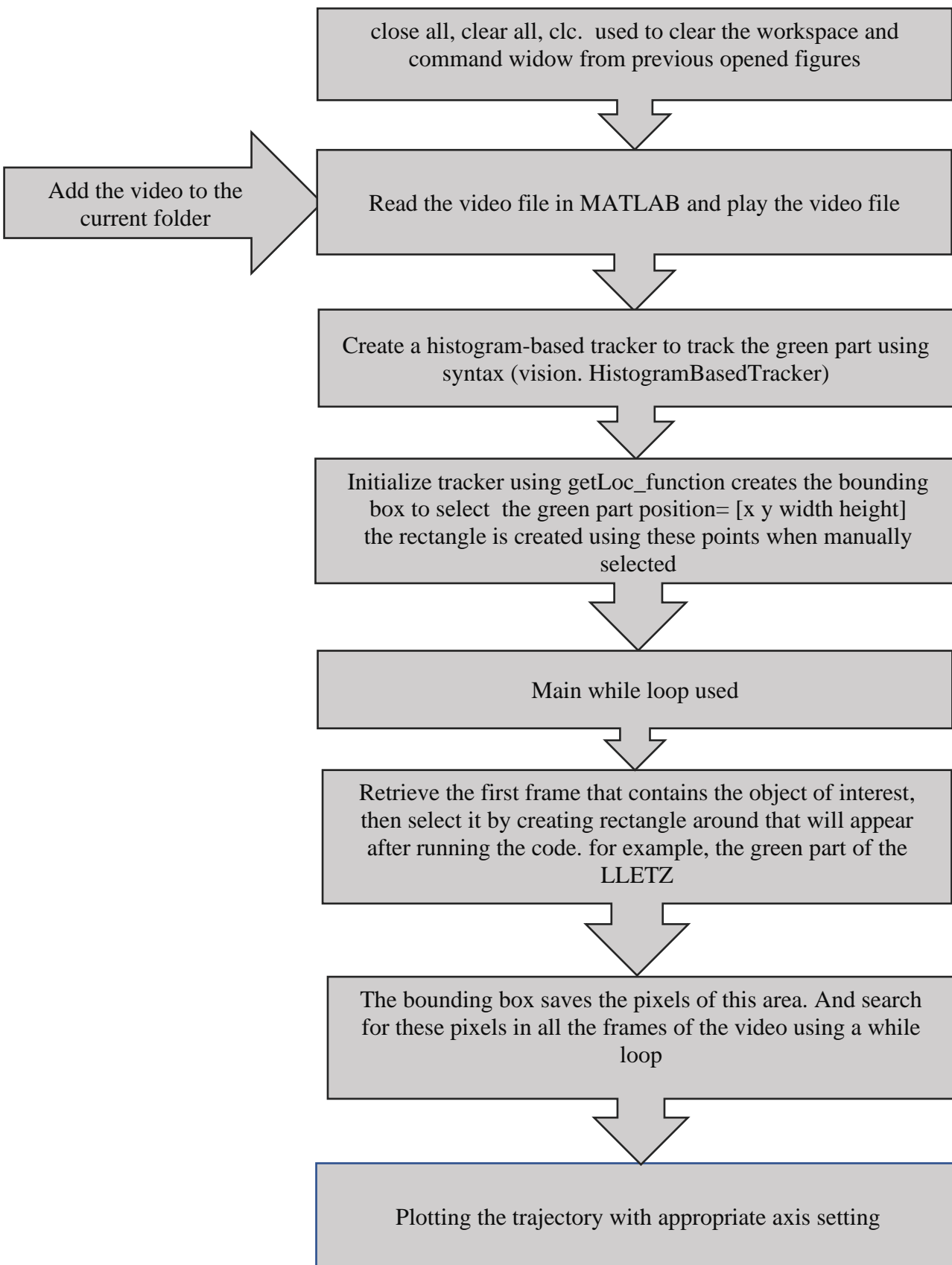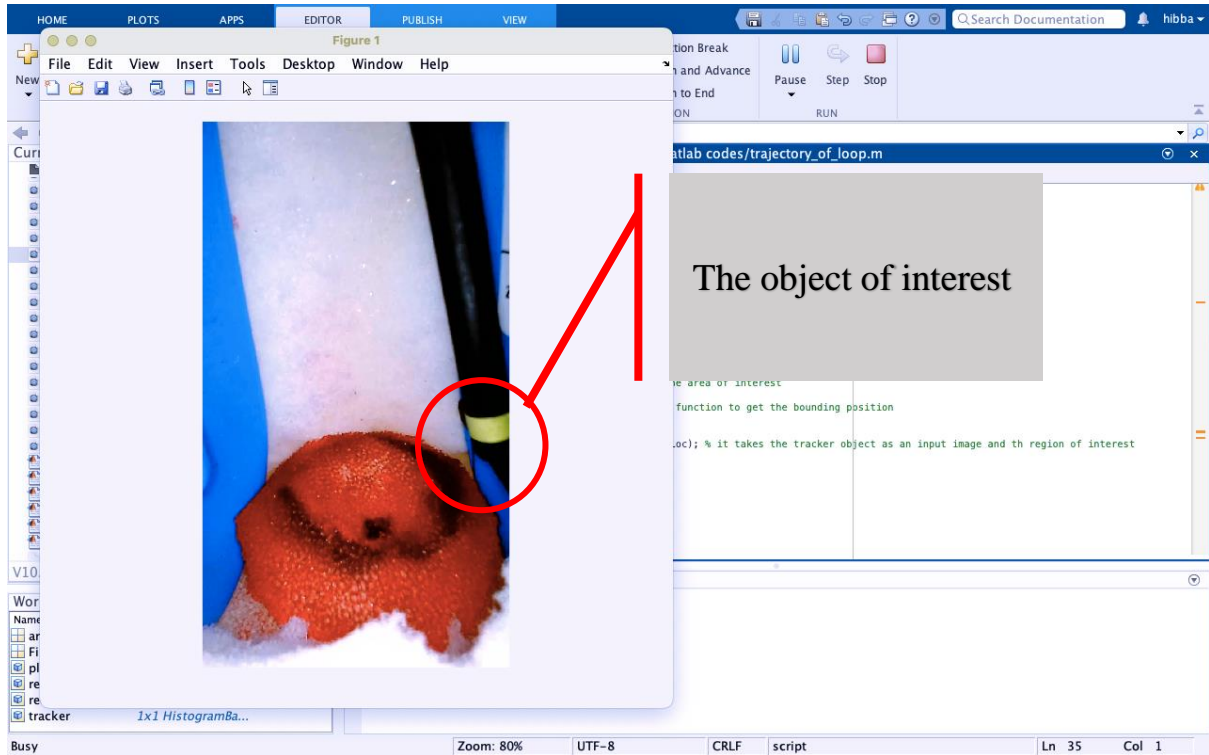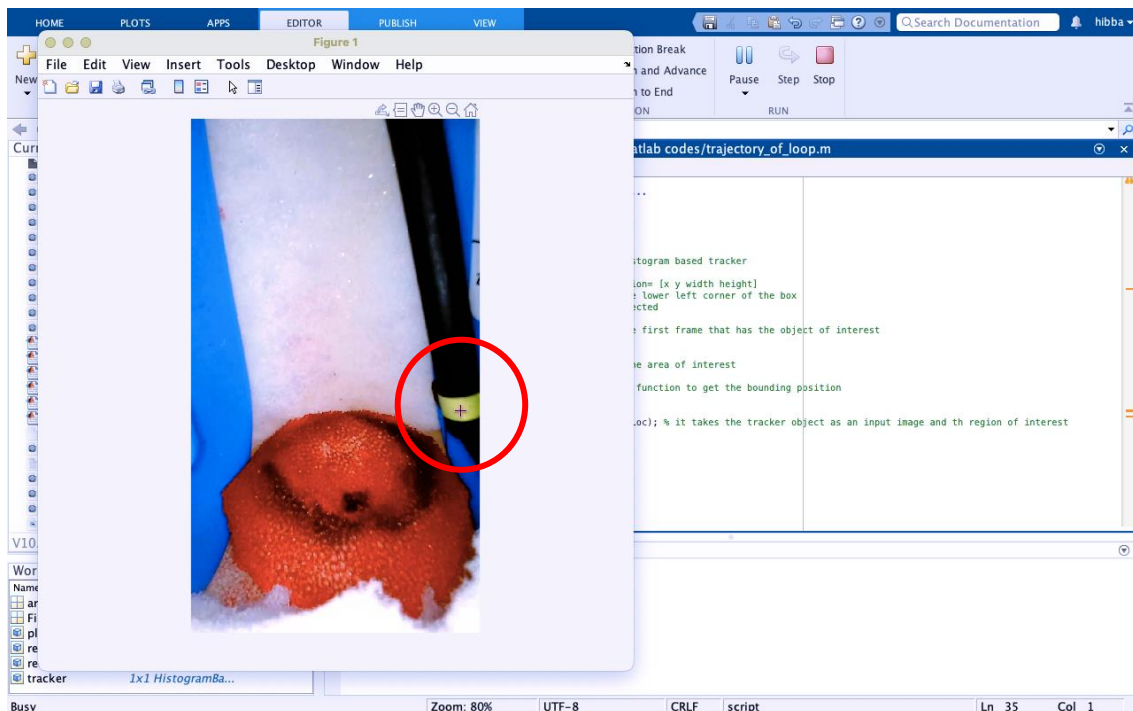Plotting the trajectory with appropriate axis setting

Figure 4.17. Block scheme of the MATLAB trajectory evaluation

4.12   How to use MATLAB code

1: After Running the code the first frame of the video should appear and the object of interest should be present in it

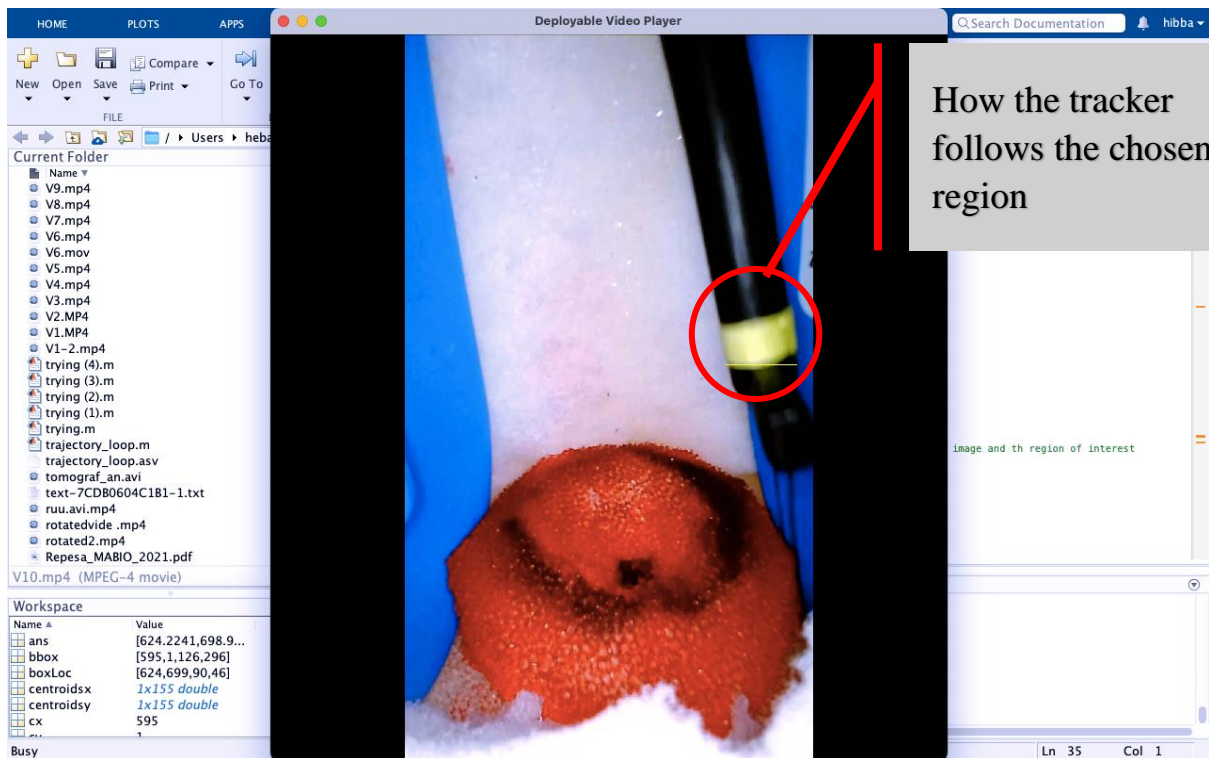2: the figure will appear automatically to select the region that looks like + sign
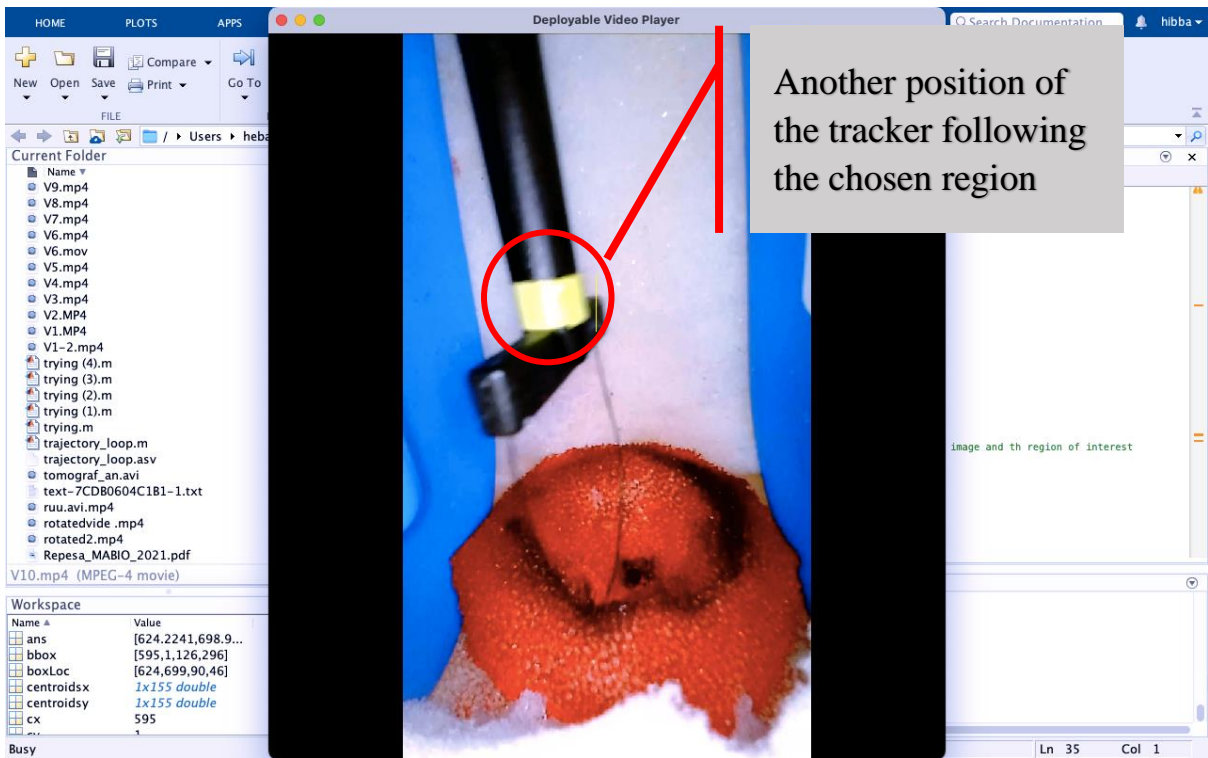
3: Select the region of interest carefully by creating a box that contained the pixels of this region only and double-click inside the box
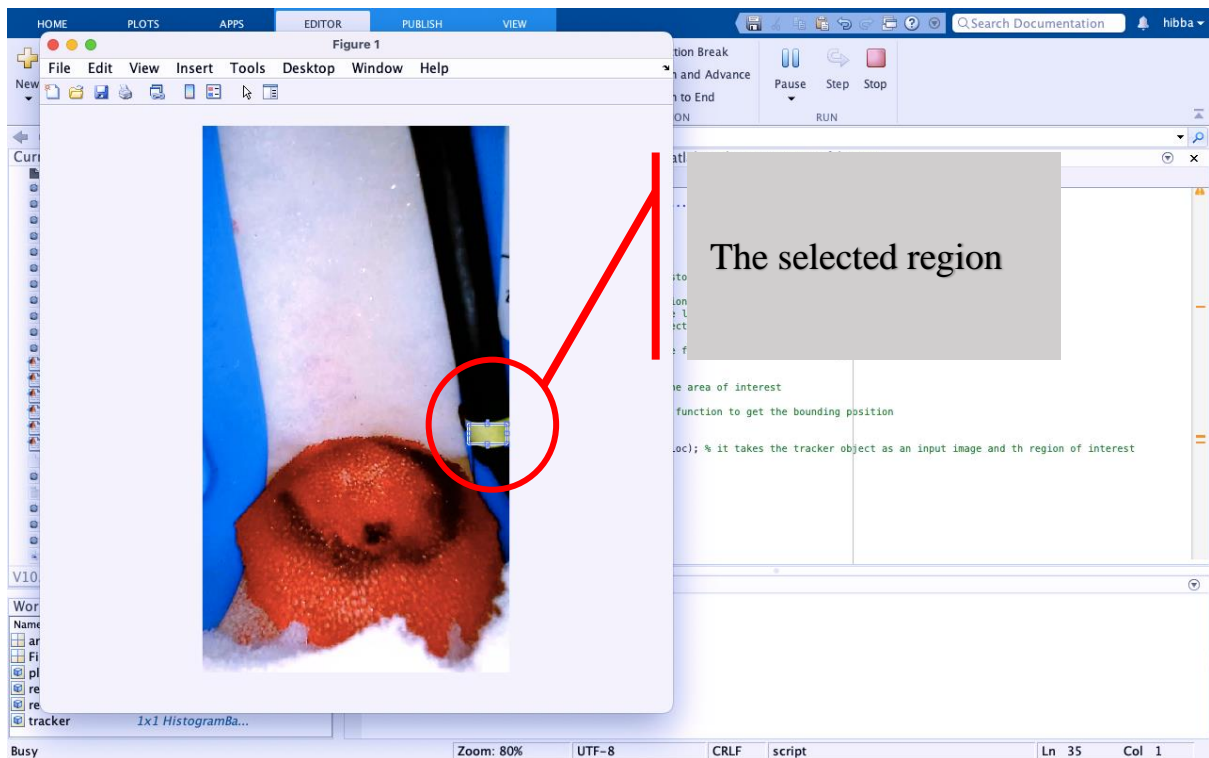
4: with the MATLAB script the bounding box initializes the tracker to trace the same pixels in all the video frames

5: Final step the graph of the LLETZ trajectory will appear automatically.

5 Results

This chapter contains six different cameras that were used in the experiment. Every camera was used individually, and the results of each camera are presented in the following subchapters.

5.1 Digital still camera

During the experiment, this camera provided some benefits, including three zoom modes, high image resolution, and a grip belt that is easy to adjust based on hand size that also aids in reaching the zoom lever. Larger sensors provide greater control over exposure settings despite shooting mode. However, its fast shutter speed, makes it ideal for capturing movement. Another significant advantage is the ease with which images can be transferred or stored using these flashcards allow you to transfer images without losing the resolution, some of the most recommended commercially available memory cards include SD, SDHC, and SDXC.

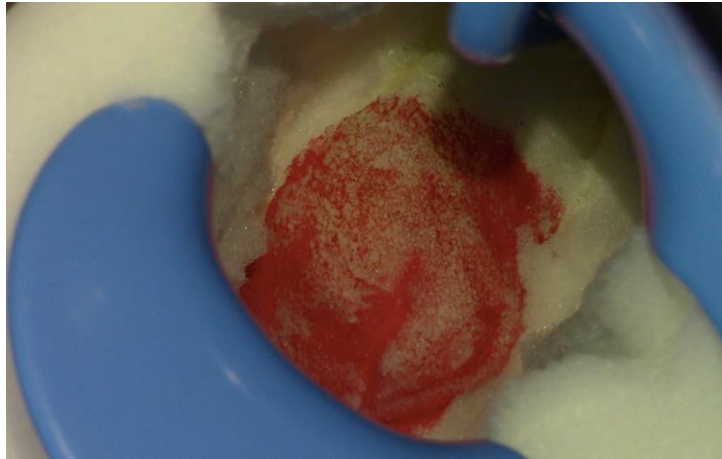*Figure 5.1 Phantom illumination using colposcope light [photo – author].*

Figure 5.2 Image taken from the semi-rigid endoscope [photo – author].

As shown in Figure 5.1, the phantom was externally illuminated using the colposcope's LED as a light source. The camera's size blocked half of the light intended to be transmitted to the phantom, leaving it slightly darkened. Figure 5.2 depicts the speculum's shadow intertwined with the cervix after the image was slightly unlighted; additionally, during the experiment, the structure of the camera was not only large but also heavy. Because the light was not fully illuminating the cervix, it was easier to use the LCD touch screen for real-time monitoring as the speculum's shadow was on the way (see figure 5.2).

5.2   WIFI TV camera

The original lens of the way WIFI camera has been changed with a CCTV lens as it has mentioned previously. The structure of the camera with the original lens makes it hard for using for this purpose as well as it lacks the required parameter, such as focus distance and wide angle, these are very important parameters to obtain clear images of the cervix with high resolution.
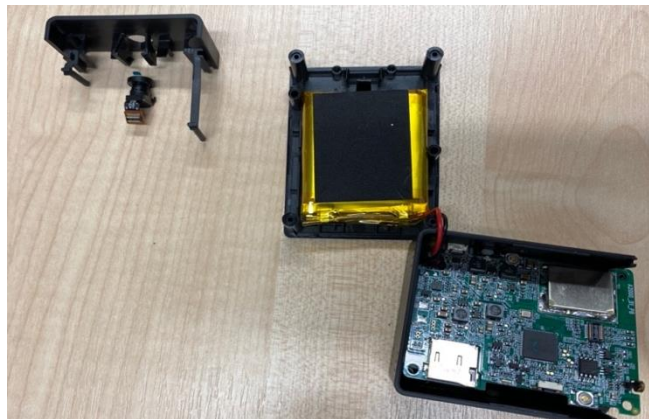

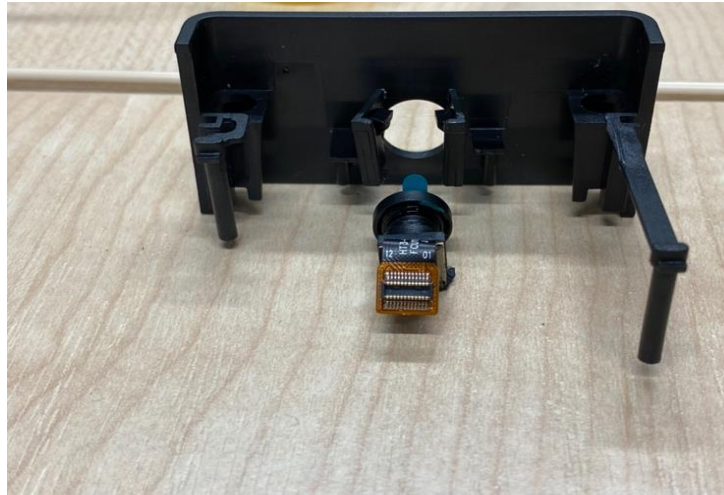*Figure 5.3 The process of unscrewing the camera box [photo – author].*

Figure 5.4 Process of replacing the original lens [photo – author].

Both Figures 5.3 and 5.4 show the process of replacing the original camera lens. The replacement process was genuinely easy, at first, the camera box noticeably has four main screws. It was necessary to dismantle these screws to open the box apart, the next step was taking out the main lens and replacing it with a TV camera lens which is shown in figure 4.6. The last step is to reconnect the box with screws.

5.2.1 Resultant image

Even though the new camera lens contains all the crucial aspects required for the test. The outcomes did not match the expectations. The camera frequently lost focus when it was near the cervix, which was one of the two main issues that were encountered. The second issue is that the camera has split into two pieces, each of which is big in comparison to the size of the phantom. This significantly impacts how much light is transmitted to the cervix and results in a lot of shadows.
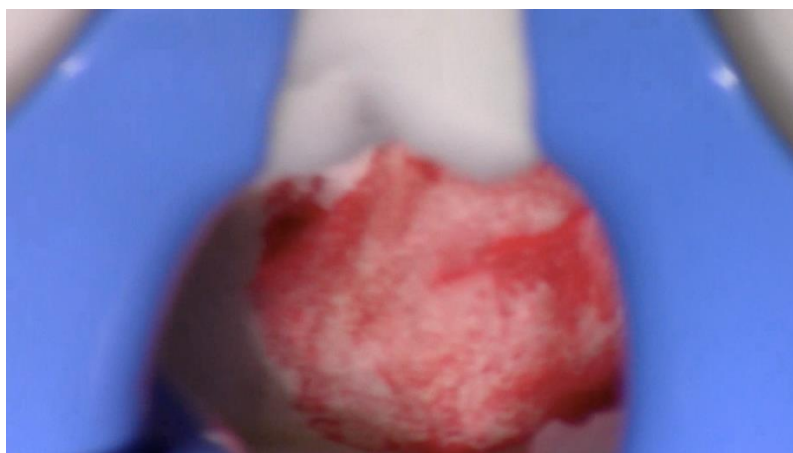
Figure 5.5 Resultant image from WIFI TV camera [photo – author].

It is clear from Figure 5.5 that despite several attempts to improve the lens focus, which stayed alternately from the cervix to the outer part of the intended structure, the resulting image was hazy with very low quality and cervical details could not be discerned.

5.3 Semi-rigid endoscope camera

The endoscope's semi-rigid tube, which served as the main support for the camera during the cervical sensing method, proved to be very helpful during this portion of the experiment by allowing the tube to be bent into any form that was necessary for the process. The semi-rigid tube's construction makes it possible to undertake circular recording of the cone of the cervix.

Figure 5.6 Resultant image from the semi-rigid camera [photo – author].

Figure 5.7 Resultant image from the semi-rigid camera after distortion [photo – author].

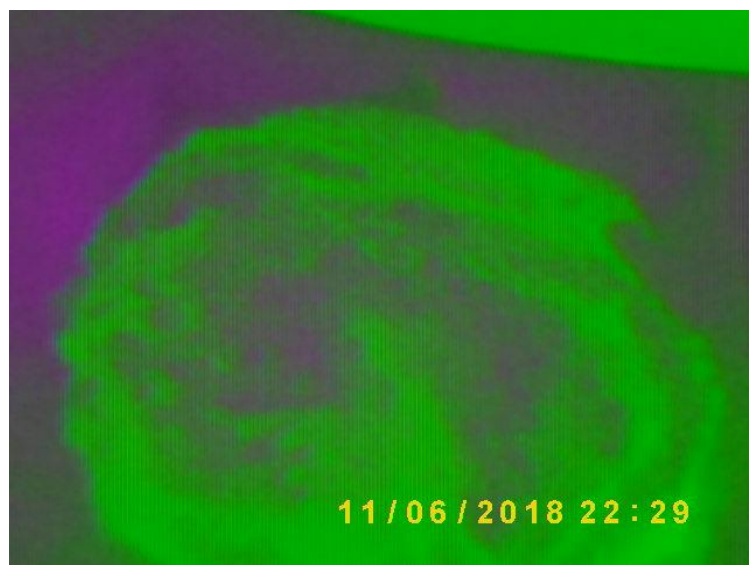The result of the camera used can be seen in Figure 5.6. One of the most important features is the ability to maintain focus even when the camera is near the cervix is one of the most crucial qualities. Regarding the camera's size, it aids in capturing views of the cone from various perspectives, including top and side views. Additionally, without the use of an external light source, the LEDs' illumination assisted to illuminate the cervix independently. But compared to the original phantom colour, it was significantly brighter. However, shortly after the image was captured, the temperature of the LEDs' light rose, gradually affecting the camera lens and causing the image's colour to shift to green as illustrated in Figure 5.7. It was therefore risky to carry on with it.

5.4   Professional endoscope

With regards to the professional endoscope, the device uses fibres with a powerful lens. This lens fixes the image onto the bundle and also deals with focusing the depth up to 10-15 cm and down to about 3 mm. As for the pinhole lens system, the smaller the aperture means that the depth is greater and vice versa. The constructed image at the top of the bundle is transmitted via a focusing lens.
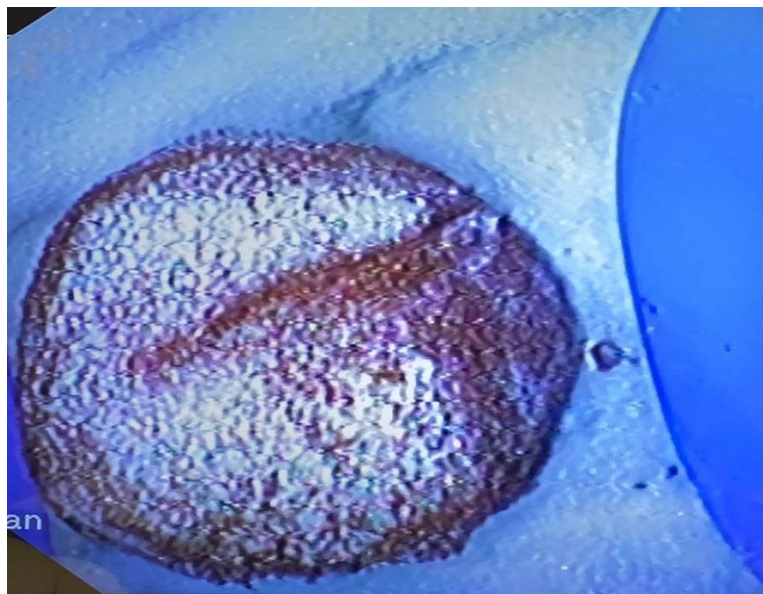

Figure 5.8 Direct view of the phantom using the professional endoscope *[photo – author]*.

The image was captured using the endoscopic camera, which is shown in figure 5.8. The resulting image was slightly crisp, making it possible to see the surface's finer

characteristics. However, the camera's inability to capture the cervix's true colours makes it an unreliable method for determining the trajectory of the LLETZ.
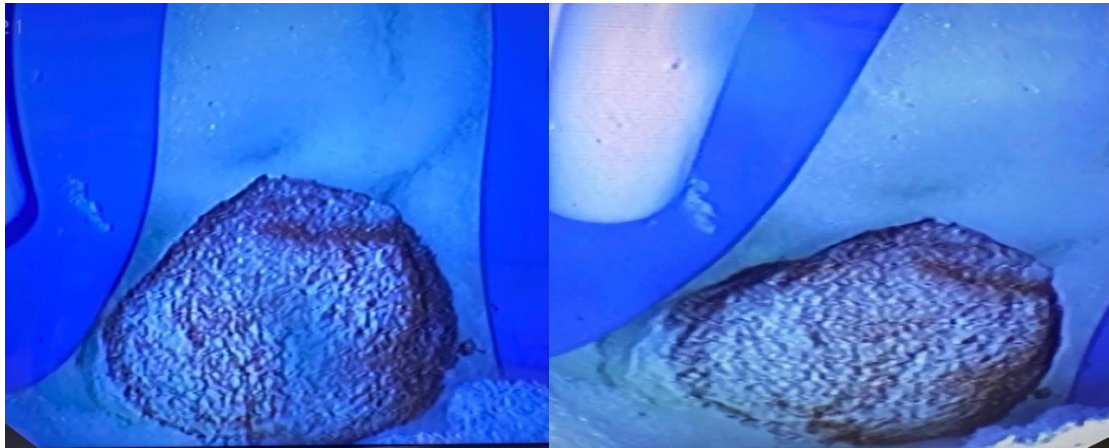

Figure 5.9 View of the cervix after penetrating the phantom from the middle *[photo – author]*.

Two main approaches were used. The first one is inserting the professional endoscope directly into the opening of the phantom to obtain a clear image of the cervix from the top. In the following figure 5.9, the second approach has been used only for this experiment as well as by using the intraoral camera and dual-lens endoscope camera, which is to penetrate the phantom from the middle for the reason of obtaining recordings from a different prescriptive of the cone shape of the cervix. This approach is not meant to be used in clinical practice since it is physically and anatomically impossible to conduct on a real patient. This is only a visual demonstration of how cervical conization can be performed from a new viewpoint, which can be useful for understanding the LLETZ excision operation which will be useful to evaluate the area after the excision has been completed.

5.5   Intraoral camera

Inserting the intraoral camera through the vaginal opening was not the ideal route for recording the conization procedure thus detecting the trajectory of the operational tool. The first reason is that the device's structural design and the lens's location make it difficult to obtain. The second reason is that the camera has a short focusing distance, which implies that it must be very close to the object that is sensed. However, recording the conization externally from the vaginal opening was considered, but due to the short distance, the further the camera, the blurrier the output videos. Therefore, all the experiments with this camera only focused on obtaining recording from the slit that was made on the top side of the phantom, because the camera is not that distant from the cervix, even though the videos came out burred the

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resolution was neglected because the m-file was able to detect the LLETZ trajectory only by inserting a bounding box on the green part that reads the pixels that create this colour and detected it in all the video frames.

The MATLAB script was able to accurately detect the movement of the operational tool before and after the conization which can be seen in Figures 5.10 and 5.12.

Figure 5.10: The trajectory path of the LLETZ before the conization intraoral camera

Figure 5.11: Illustrates the shape of the cervix before conization with the tool trajectory intraoral camera

Figure 5.12: The trajectory path of the LLETZ after the conization with a rotated intraoral camera
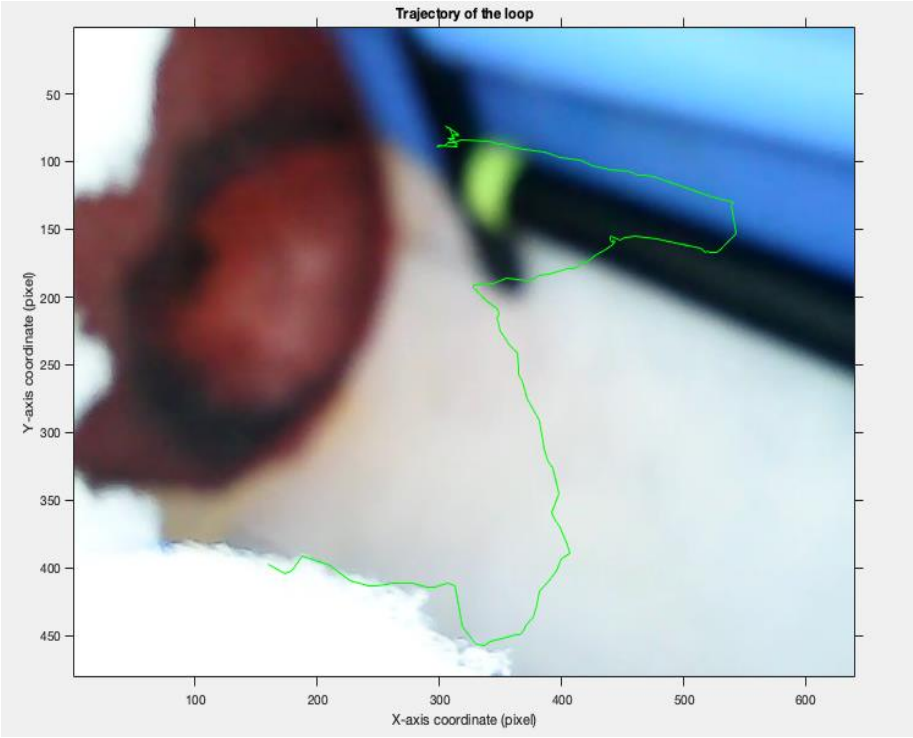
Figure 5.13: Illustrates the shape of the cervix after conization with the tool trajectory with a rotated intraoral camera

5.6   Dual-lens endoscope camera

The dual-lens endoscope camera was the most appropriate camera for recording the conization operation because the design of the structure is small and long enough to be inserted deeply into the vaginal canal, along with LLETZ, to obtain good sensing of the procedure. Therefore, it was possible to record the entire procedure from the vaginal orifice, unlike the Intraoral camera. The output results of this camera have high resolution and reliable true colours can be seen in figure 5.14.
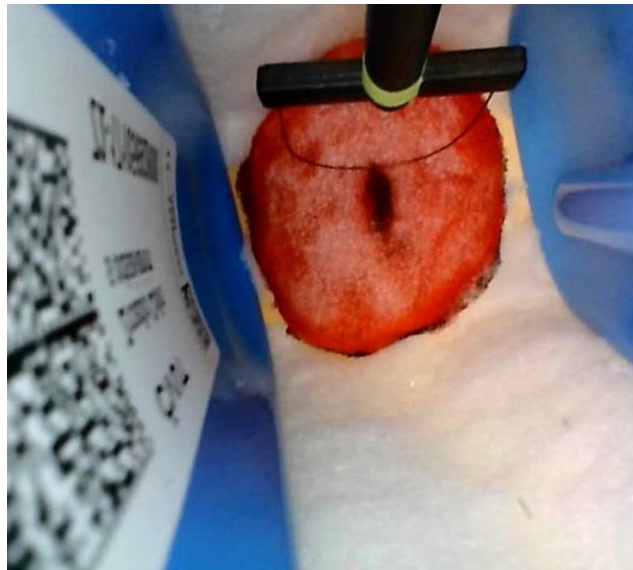
Figure 5.14: Result output image of the dual-lens camera using the top lens [photo – author].

Because of its position, the side lens of the camera played no role in the experiment and inserting it into the phantom orifice would be useless, as was the case with the intraoral camera. The device's screen displays both cameras at the same time from different angles. Since this camera was not used, this feature was unnecessary. The output images can be seen in figure 5.15.

Figure 5.15 Result output image of the dual-lens camera using both lenses at the same time [photo – author].

All results obtained were only from the top lens of the device. This experiment's results were also analysed using the same MATLAB script. the tracker used the video files provided to track the movement of the LLETZ.
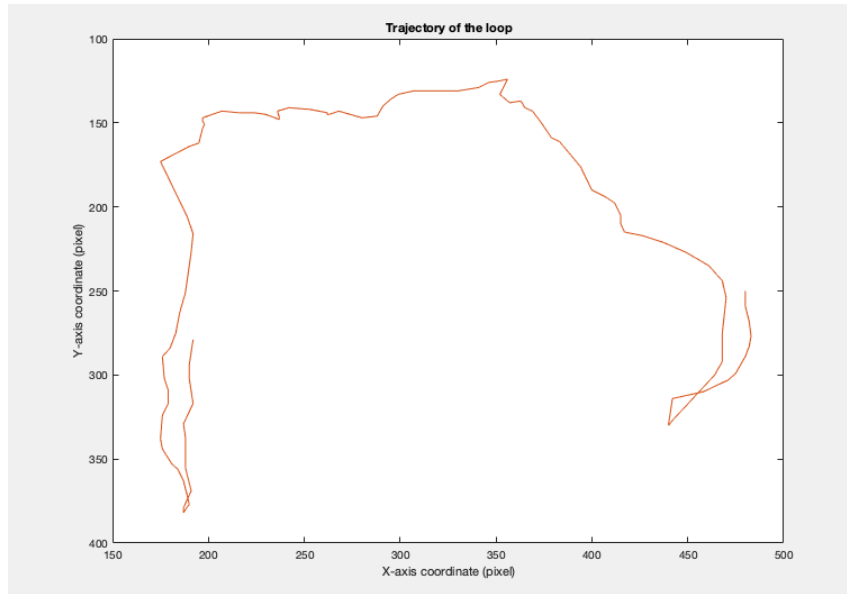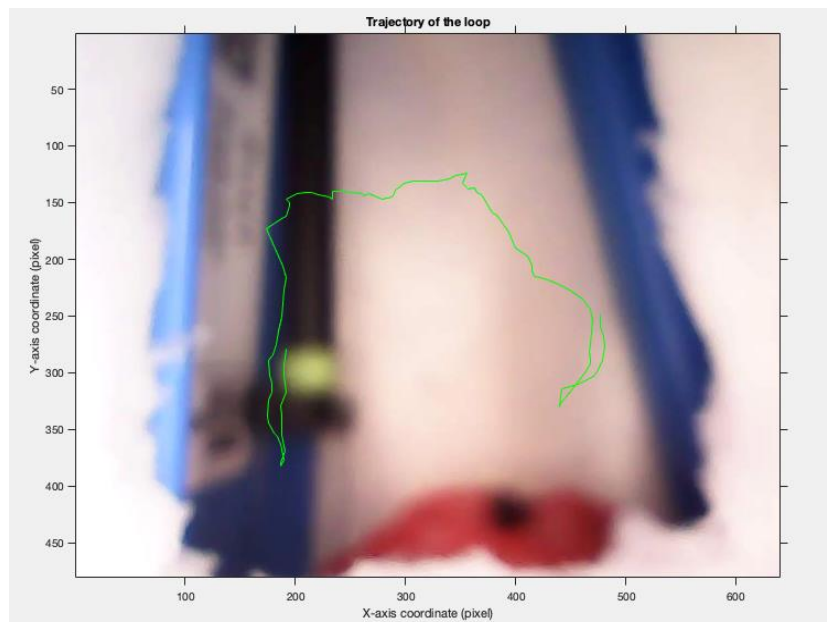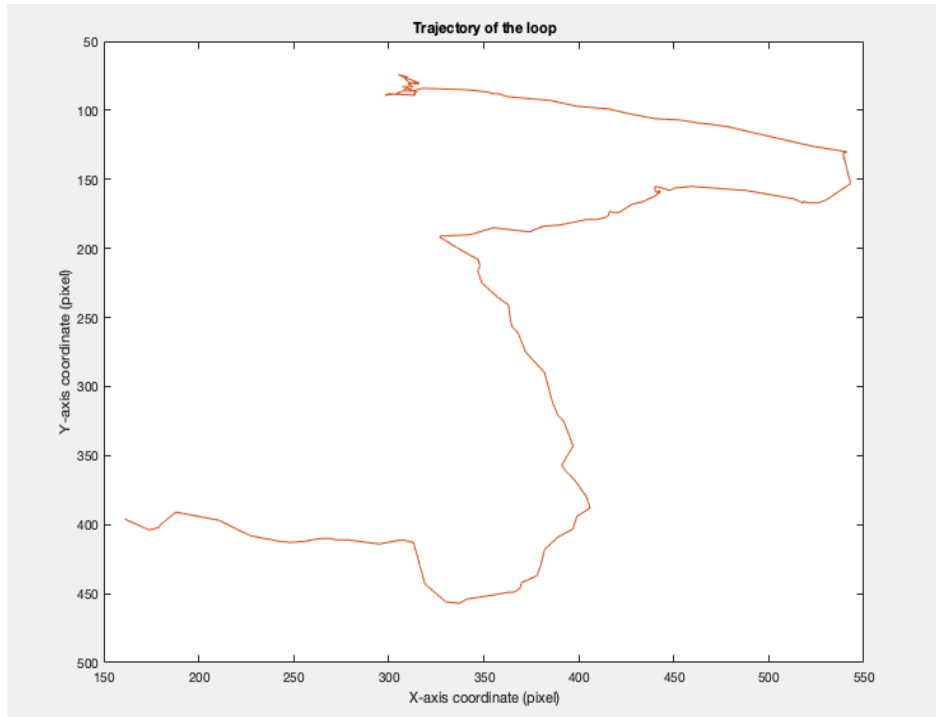
Figure 5.16: The trajectory path of the LLETZ before the conization

Figure 5.17: Illustrates the shape of the cervix and trajectory path of the LLETZ before the conization

Figure 5.18: The trajectory path of the LLETZ after the conization
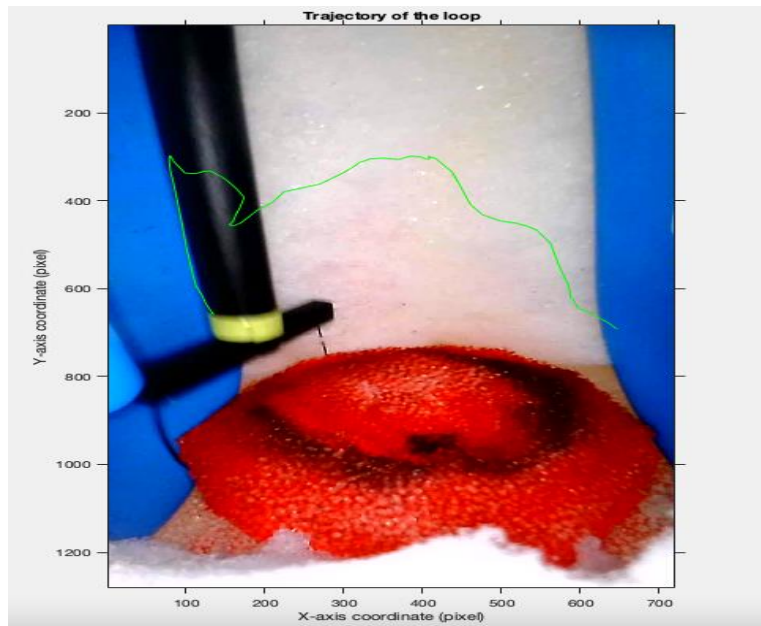
Figure 5.19: Illustrates the shape of the cervix and trajectory path of the LLETZ after the conization

6 Discussion

The key finding of this pilot study is the ability to track the path of the operational tool through recorded video files of the cervical conization procedure that was filmed utilizing small cameras. To fu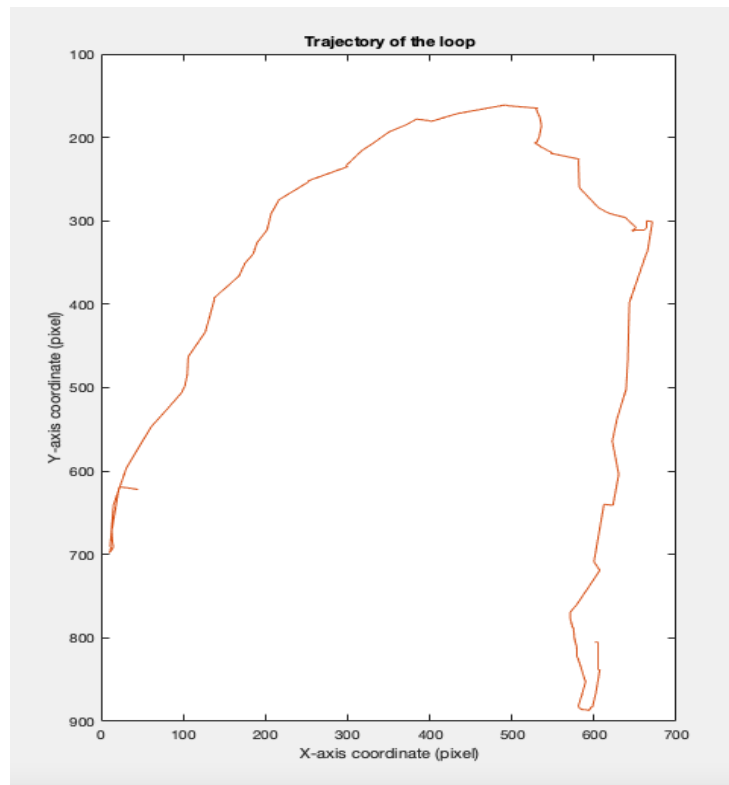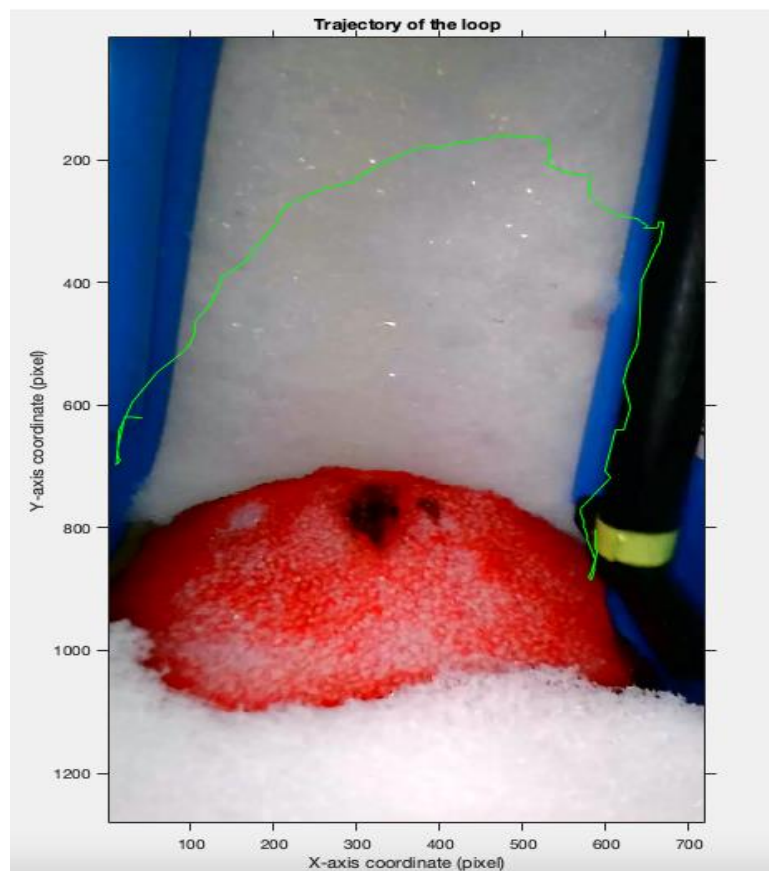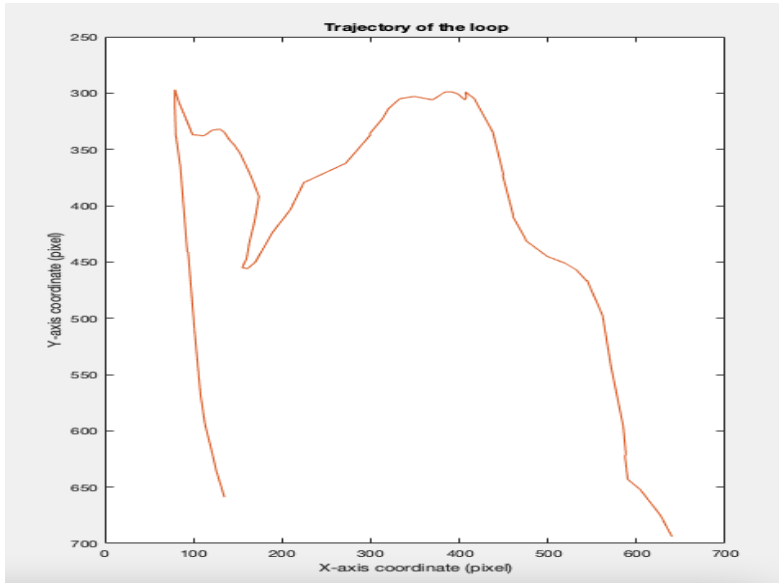lfil the main required output of this project, each of the aforementioned cameras was used and tested separately to record the cervix. A comparison was made after evaluating each device to choose the ideal one, as shown in Table 6.1 Although no camera was perfect, some were better compared to others.

Number of used cameras	Advantages	Disadvantages	Ideal (10 is perfect 1 is imperfect)
1- Digital camera	- Good optical zoom and advance zoom - Stabilization	The size of the camera is too large	2
2- WIFI TV camera	- Automatic change of resolution with change of light	- The additional lens is too large - Additional light is required	1
3- Semi-rigid endoscope camera	- Due to its small size can perform internal recording	- The temperature of the LEDs rises and changing the performance of the lens	3
4- Professional endoscope	- Light source - Small size + internal recording	- not true color	6
5- Dental camera	- Small camera + wide angle lens	- Non-rotating camera -not suitable for internal recording	7
6- Dual lens endoscope camera	- Tow wide angle lenses - Small size +internal recording	- Side lens was not useful for this experiment	8

Table 6.1 show the comparison between all devices used

Table 6.1 shows why the intraoral camera, and the dual-lens endoscope camera were found to be the best cameras among the rest for this experiment based on the results of all the cameras that were employed. Since the conization procedure is invasive, it is one of the potential limitations of this experiment. As a result, the project took a different turn by cutting a slit in the phantom, which is only for experimental purposes and is not possible in outpatient clinics. This method was intended only for analysing the trajectory of the LLETZ before and after conization from two different perspectives.

The size of the dental camera and its minimum focusing lens distance caused the first conflict to arise throughout this study. Figure 4.14 (A) and (B) illustrate how the intraoral camera's construction differs in size, with the portion containing the lens being smaller than the body of the device itself. However, depending on the fixed position of the lens makes it challenging to record internally because the lens will not face the cervix. On the other hand, it was possible to record the cervix externally, but due to its short focus distance, the output video came out blurry.

The dual endoscope camera was the first ideal camera for this experiment due to its small structure, which allowed both the LLETZ and the camera to be inserted inside the phantom. Furthermore, due to the position of the camera as can be seen in figure 4.15, the conization procedure can be recorded from two different angles: internally from the vaginal orifice or through the slit on the top side of the phantom.

The analysis method used after conducting all videos of the procedure was accomplished by using a MATLAB script that detects the green part of the LLETZ, as shown in figure 4.6. The region of interest was manually selected by drawing a bounding box around the green part of the operational loop, this box saves the number of pixels of this region and detects them in every frame of the video file. In this way, tracking the trajectory path of the LLETZ was achieved.

The trajectory of the LLETZ has been successfully traced with the help of the MATLAB code can be found in the appendix. Even though this was not what was planned in the initial phase of the project. The very first limitation that occurred during this stage was that the focus was on detecting the trajectory of the loop based on the green colour, and not all videos have the same colour ratio for this part, the lighting is constantly changing in different videos and within the same video thus the pixels of the RGB channels are changing as well,

the bounding box method was found to be more practical because of manual selection of the region enabling it to function for all video files. While selecting the green part it was considered not to include other than the part of the interest in this box.

Finally, the results of using the bounding box of the videos which performed the recording of conization from the slit on the top side of the phantom were successfully obtained which can be seen in Figures 5.17 and 5.19 the trajectory will be very close to both figures, but there are some obvious differences due to hand tremors. On the contrary, the recordings of the conization performed from the vaginal orifice of the phantom were poorly detected because the bounding box was rapidly losing the selected region and distracted by the surroundings which can be seen in Figure 6.1
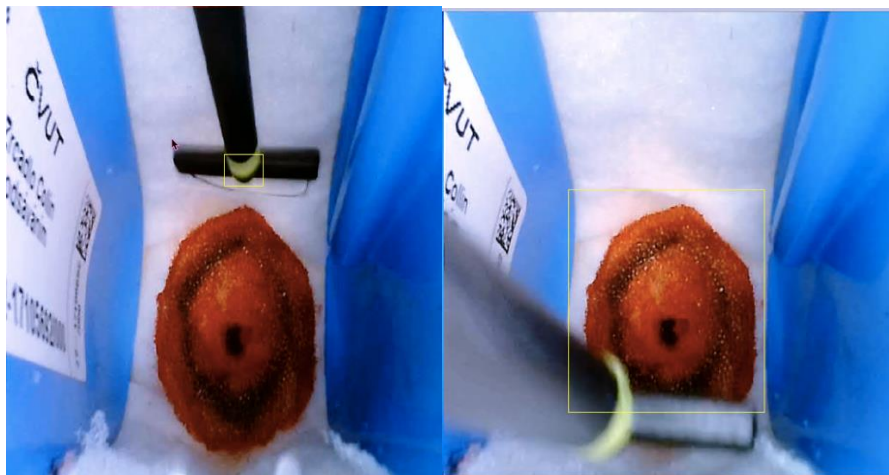
Figure 6.1 Failed tracking of the green part [photo – author].

Another way to determine the accuracy of the LLETZ excision of the transformation zone is the dimensions and the volume of the specimen measured at the time of the procedure, before formaldehyde fixation. The volume must be measured by immersing the specimen in a graduated cylinder and employing the Archimedes fluid displacement technique. The measured volume must be compared to the calculated volume using different volume formulas, such as a cone, cylinder, parallelepiped, and hemiellipsoid. The relationship between the calculated volume (using the dimensions of thickness, length, and circumference) and the measured volume of the specimen is the primary outcome measure[28].

For future recommendations the conflict of detecting the trajectory of the LLETZ can be resolved using computer vision, where the deep train of the model is capable of recognizing the features of the object directly from the data with which they are trained, eliminating the need to manually extract features. The system's principle is inspired by the structure of the human brain, hence the name. It is made up of three types of layers can be seen in figure 6.2: input, hidden, and output. The hidden layer processes the signal received by the input layer, and the output layer decides or predicts based on the input data. Each network layer is made up of interconnected nodes (artificial neurons) that work together to perform computations [29].
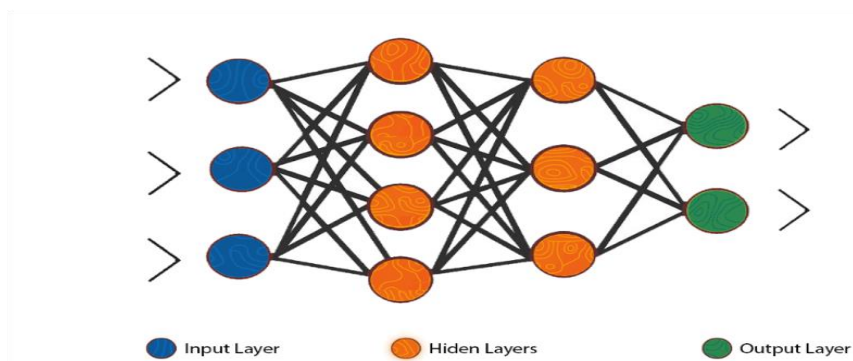

Figure 6.2 The architecture of a neural network, each layer consists of nodes [29]

7 Conclusion

In conclusion, the pilot project aims to concentrate on sensing the cervical conization operation with the potential to analyse the LLETZ's trajectory. Since this process is invasive, the recording must be carried out internally. It was essential to examine a variety of cameras and choose the most suitable ones for this operation.

The study was carried out using a phantom that resembled the real cervix. During the experiment, two different methodologies were used to record the cervical conization procedure. The first approach is to record the conization procedure through the vaginal orifice. The other method is to cut a slit inside the top side of the phantom and record through the slit.

Many attempts have been made to select the best camera, and based on the results, it was determined that the intraoral camera and the dual-lens endoscope camera were the most ideal among the other cameras.

The results of the LLETZ trajectory were successfully detected by the MATLAB script that uses the video files obtained from the slit on the phantom from both cameras. As regards the recordings of the conization performed from the vaginal orifice of the phantom were poorly detected because the MATLAB code failed to detect the trajectory of the loop. Detecting the excision quality using special cameras is still a new approach that needs further investigating in the future.

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Appendix A: MATLAB script for tracking the trajectory of LLETZ

```matlab
close all
clear all
clc
% video reader and video player
Read_video = vision.VideoFileReader('insert video file',...
    'VideoOutputDataType','double');
Play_video = vision.DeployableVideoPlayer;


% Create a tracker of the green part
tracker = vision.HistogramBasedTracker; % histogram based tracker

% Initialize tracker of the green part position= [x y width height]
% bounding box coordinates x& y represent the lower left corner of the box
% let the region of interest be manually selected

First_frame = step(read_video); % retrieve the first frame that has the object of interest

imshow(First_frame); % display frames
rectang = imrect; % create rectangle around the area of interest
wait(rectang)
boxLoc = getLoc_function(rectang); % utility function to get the bounding position
imgYcbcr = rgb2ycbcr(First_frame);
disp(imgYcbcr);
initializeObject(tracker,imgYcbcr(:,:,2),boxLoc); % it takes the tracker object as an input image and the
region of interest

% Track object
frames = 1;

%create empty arrays for centroids

centroidsx = [];
centroidsy = [];

while ~isDone(read_video)
    First_frame = step(read_video);
    imgYcbcr = rgb2ycbcr(First_frame);
    [bbox,~,zeros(frames)] = step(tracker,imgYcbcr(:,:,2));
    bbox;
    out = insertShape(First_frame,'Rectangle',bbox);

    cx = bbox(1);
    cy = bbox(2);

    centroidsx(frames) = cx;
```

```matlab
        centroidsy(frames) = cy;
        plot(centroidsx,centroidsy);
        step(play_video,out);
        frames = frames + 1;
end

imshow(First_frame)
axis on
hold on
plot(centroidsx,centroidsy,'g');

% Graph config

title('Trajectory of the loop');

 xlabel('X-axis coordinate (pixel)')
 set(gca, 'YDir', 'reverse');
 ylabel ('Y-axis coordinate (pixel)')

 disp('Finished');
```

the fused function in the MATLAB code above.

```matlab
function [boxLoc,centroidLoc] = getLoc(hrect)
bbox = getPosition(hrect);

boxLoc = round(bbox);

centroidLoc(1) = bbox(1) + (bbox(3)/2);
centroidLoc(2) = bbox(2) + (bbox(4)/2);

end
```

Appendix B: Contents of the enclosed CD

- The complete bachelor thesis
- MATLAB script codes (trajectory_of_loop.m)
- Video data files (after conization dual lens camera .mp4, after conization oral camera.mp4, before conization dual lens camera.mp4, before conization oral camera camera.MP4)