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A Review of Cervical Cancer Imaging: The need for a Smart Low-end Cervical Cancer Image Acquisition System

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***Abstract*— Cervical cancer (CC) is a disease which can be avoided or detected by undergoing regular screening tests to observe for abnormalities in the cervix. Research shows that there is a lack of population-wide screening program and limited medical experts to carry out screening exercises, especially in low resource settings. This is due to the lack of awareness and limited access to health services. The use of smartphones as a screening tool has been suggested to increase the reach of screening programs to low resource settings. The reason is that as compared to other cervical cancer image acquisition (CCIA) tools, the smartphone is less expensive and can be used by physicians and non-physicians as well. To function as a CCIA tool, the smartphone has to possess certain specifications and properties. This paper reviews CCIA systems, highlighting how they were used, and features considered in choosing them. It exposes why the CCD cameras are mostly employed in image acquisition during cervicography. The need for a low-end CCIA system and its limitation is also discussed alongside reasons why the smartphones are ideal as a CC screening device in low resource settings. The paper goes further to review smartphones that have been used in CCIA based on properties that deems it acceptable as a CCIA tool and their limitations. Some additional features/properties have been considered to maximize the functionalities of the smartphone as a CCIA tool, thereby extending the reach of CC screening. It has been deduced from this paper that Samsung Galaxy S5 is more suitable for low-end CC screening based on properties that have been carefully considered.**

Keywords—: Smart systems, Cervical Cancer, Medical Image Acquisition, Smartphones

I. Introduction

Cervical cancer is the fourth most predominant type of cancer affecting women worldwide, with over 85% of the cases occurring in less developed countries [1]. The disease is found to be the second most prevalent type of cancer in Nigeria [2]. It is caused by the Human Papilloma Virus (HPV), which if it lingers for years in the cervix, could cause some cells to become cancerous. It takes about 15 years for the HPV to develop into cancer [3]. This disease could be avoided or detected by undergoing regular cervical screening tests to observe for abnormalities in the cervix. The three methods of screening are cytology, colposcopy, and Visual Inspection with Acetic acid (VIA) or Lugol Iodine solution (VILI). During the screening process, the cervix or images taken from the cervix are analysed for colour, cell, or textural changes. Obtaining the image with the help of a camera before analysis, have proven to save huge resources, reduce human error, increase screening efficiency, and enhance screening accuracy [1]. This process is known as cervicography.

In developing countries, the lack of population-wide screening programs and medical experts to carry out cervical cancer screening exercises, has made cervical cancer endemic [5]. This is due to lack of awareness, limited medical experts, and lack of resources and access to health services [6]. As a result of these limitations, the need for researches aimed at extending the reach of cervical cancer screening to low resource settings have been created. The use of smartphones as a standalone screening tool has been suggested to increase the reach of screening programs in low resource settings [5]. This is achieved by integrating an automatic cervical image classification system with a smartphone, resulting in a less expensive system that can be used not only by the medical experts, but by non-physicians as well. Since the smartphone does the image acquisition, it has to possess certain properties to function as a cervical cancer image acquisition (CCIA) tool. Therefore, based on certain suitability qualities, this paper reviews the smartphones and digital cameras that have been used so far as cervical cancer screening tools. Screening the image acquisition device is the first step towards an automated cervical cancer screening exercise. At the end of the paper, the most suitable smartphone that has been used so far as a CCIA tool is discussed based on CCIA system's suitability qualities. This could assist health care workers in making prompt decisions as to which device is most suitable for a specific screening exercise, especially in cases where resources are limited.

The methods of cervical cancer screening are discussed in Section 2. Section 3 reviews the CCIA systems and features considered when using a digital camera for cervicography. Section 4, reviews smartphones that have been used in CCIA based on properties that deems it acceptable as a CCIA tool and their limitations. The need for a low-end CCIA system and its limitation is also discussed alongside the reason why the smartphones are ideal as a CC screening device in low resource settings. Additional features are also suggested here to maximize the functionalities of the smartphone as a CCIA tool, thereby extending the reach of CC screening.

VI. Methods of Cervical Cancer Screening

The methods of cervical cancer screening are colposcopy, cytology, and Visual Inspection with Acetic acid (VIA) or Lugol Iodine solution (VILI). A brief explanation of the various screening methods is as follows.

A. Colposcopy

Colposcopy is a diagnostic procedure in which the cervix is examined using an instrument called the colposcope [2]. The colposcope illuminates and magnifies the view of the cervix, giving the pathologist a proper view of the cervix. A colposcopic examination is performed to identify the severity of the dysplasia to enable the effectiveness of necessary measures. The examination is subjective to a physician's interpretation which affects the accuracy of the result. Shrivastav *et al* reported that Colposcopy suffers from low specificity which results in unnecessary biopsies [3]. A biopsy involves taking an affected area of the cervix and performing more tests on it. Also, the use of a colposcope is not feasible in low resource settings.

B. Cytology

The cytological screening can be performed in one of two ways: the Papanicolaou test known as the Pap smear test [4], and the Liquid based cytological screening. During the Pap smear test, cell samples are collected with a brush and transferred to a slide for microscopic examination of abnormalities. In the case of the liquid-based cytology, the brush is washed in a liquid preservative and then taken for further testing in the laboratory.

C. Visual Inspection with Acetic Test (VIA Screening Test)

The VIA screening test is mostly used in low resource settings. It is performed by applying Acetic acid or Lugol's iodine to the cervix. A change in the colour of the cervix could in some cases, be translated as cervical cancer [5, 6]. Hence, the decision or diagnosis obtained from VIA tests is not always accurate. Being a test, which is based on the expertise of a pathologist or trained medical personnel, its result is always subjective. Also, the number of the trained medical personnel versus the growing population of patients is really low. In the light of this, researches on automated detection of cervical cancer came to birth. The VIA or VILI is the most regular screening method used in low-resource setting.

II. Cervical Image Acquisition

The first stage of every screening exercise is the observation of the cervix. The cervix is viewed in two ways; by using a colposcope to magnify and illuminate the cervix for a proper view of its anatomy, and by cervicography. Cervicography entails obtaining images of the cervix and analysing them for abnormalities. This method has proven to save huge resources, reduce human error, increase screening efficiency, and enhance screening accuracy [4]. Cervical images are usually acquired using cameras, microscopes, or slide scanners [7]. Several kinds of digital cameras, micro-scopes, and phone cameras have been used for this purpose.

In most cases, cervicography requires a microscope which is specially adapted with a camera port, an adapter for the attachment of the camera to the port, and a camera [8]. Almost any combination of a digital camera (including phone cameras) and a microscope can be used for cervical image acquisition. The use of microscopes such as the Olympus BX 43 [1] [9], Olympus BX 53F [10], Olympus CX 41 [11], Olympus BX 41 [12], Olympus BX 40 [13], Olympus BX 51 [14], and other brands of microscopes such as the Leica ICC50 [15] [16], Leica DM300 [4], Keyence BZ – X700 [17], and the Nikon Biophot [18], has been reported in previous studies.

In most cases, the microscopes were combined with digital cameras that use either the Charge-Coupled Device (CCD) or the Complementary Metal-Oxide Semiconductor (CMOS) image sensors. While the CMOS image sensor camera consumes less power and are less expensive than the CCDs, the CCD cameras produce higher quality images and are more tolerant to noise as compare to the CMOS. Also, the CCD tends to have more pixels than the CMOS.

As a result of these differences, the CCD cameras are mostly employed in image acquisition where the focus is to produce high quality images with high resolution and excellent light sensitivity. Hence, most researches on cervical image acquisition [4][10-15] and other medical image acquisition [17] [18] [19] [20] [21] [22] that use a combination of digital camera and microscope, utilize the CCD image sensor camera.

Examples of such cameras are the Infinity I Lumenera [10], Olympus SP 350 [11], Jenoptik Optical [12], QImaging G03 [13], and the Hamamatsu ORCA-05G [14]. Table 1 list the image acquisition devices as used in various studies.

TABLE I. A list of the image acquisition systems

Author/Year	**Image Acquisition Device Configuration**	**Camera (CCD/CMOS)**	**Mounting Device** **Microscope/Slide Scanner**
[1]	Camera IDS UI-3370CP-C-HQ on microscope/ 300 x 300 resolution images/jpg/8 bit gray depth	CMOS	Olympus BX 43
[10]	Camera Infinity I Lumenera on microscope	CCD	Olympus BX 53F
[15]	Leica high resolution camera on microscope/2560 x 1920 image resolution/jpg/24 bits color depth	CCD	Leica ICC50/40x resolution
[11]	Digital camera Olympus SP 350 on microscope/image size 132 x 158 pixels/jpg/	CCD	Olympus CX 41/resolution 80 megapixel
[23]			Whole-slide scanner KF-PRO-120

[4]	Digital camera on a microscope	CCD	Leica DM300/40x objective lens
[17]	Initial Image resolution 640 x 480 sq. pixels/ final image resolution 160 x160 sq. pixels		Microscope Keyence BZ-X700
[18]	CCD camera on a microscope/image resolution 491 x 652 x 128 pixels/jpg	CCD	Microscope Nikon Biophot/40x magnification
[19]	A CCD camera Hyperspectral imaging system	CCD	Cri imaging system (Caliper Hopkinton)
[20]	Nuance FX system		Fluorescent microscope/20x objective
[21]	CCD camera on microscope/128 x 128 image resolution/jpg	CCD with a Liquid Crystal Tunable Filter (LCTF) multispectral image sensor filter/LCTF bandwidth 5nm	Classical microscope
[22]	CCD camera on microscope	CCD with LCTF filter/LCTF bandwidth 5nm	Classical microscope
[24]			Scanner: Mylab twice ultrasound system
[25]			Microscope Leica ICC50HD/400x resolution
[12]	Camera Jenoptik optical system 1.4 megapixel/image resolution 1360 x 1024 pixels/jpg/24 bit RGB	CCD	Olympus BX 41 microscope/20x objective
[13]	Camera QImaging G03 on microscope/jpg/image resolution 1024 x 768	CCD	Microscope Olympus BX 40
[9]			Microscope Olympus BX 43/40 x magnification
[14]	Digital camera Hamamatsu ORCA-05G/jpg/8 bit grey depth	CCD	Microscope Olympus BX 51/40x magnification

III. The Smartphone as a CCIA tool

A number of researches made use of smartphone cameras for cervicography. In the last few years, an exponential increase has been documented in the use of smartphones as a stand-alone cervix image acquisitions device as presented in [5],[26-39]. According to cisco [41], by 2021, more people will have smartphones than running water. The major advantage of using smartphones for cervicography is the availability of camera equipped cell phones all over the world. Currently, inexpensive smartphones with good quality cameras are available. The use of a smartphone with an application to capture images during VILI or VIA, may be a low-cost screening approach [36] [38]. This allows for low-cost diagnosis.

Another advantage of using smartphones as reported by Kudva et al [42] is the potential of assisting health care workers who are not physician in the translation of VIA results, consequently extending resources to get to more patients [5]. This is very important because the success of a VIA program relies on the training and experience of the health care workers involved. Hence, a strategy is required to assist non-physicians and novice health care staff [34].

The progress in smartphone imaging devices and the ease of use has encouraged the use of smartphone cameras in cervical cancer screening. However, the smartphone has to possess certain properties for it to be acceptable as a CCIA tool. The study by Louis Auguste et al[33] tested the iPhone 4, iPhone 5s, Sony Z2 and the Samsung Galaxy S3 for image resolution and camera definition and resolved in using the iPhone 5s as a result of its full resolution image capture and high definition camera. Another study by Holmen et al[27] simulated several low quality images, specifically less than or equal to 5MP camera. The result from the study shows that the higher the camera definition, the better the quality of images produced. Yeates et al[30] tested different smart phones for resolution and selected the iPhone 5S for its high image resolution and clarity. A few other researchers have listed the properties associated with the choice of smartphone used in their research and why the property is important in cervical cancer image acquisition. In this paper, we sum the most important properties as follows:

a. A Light-Emitting Diode (LED) to illuminate cervix (Squamous epithelium) tissue [5] [26] [31][36] [37] [39].

b. A higher resolution phone camera: A higher resolution phone camera is required to obtain high image resolutions. This is important as it helps in displaying all the intricate details such as the shape of cells, vascular patterns, and lesion margin on the cervix [30] [31] [33].

c. A high definition camera or a high camera sensor produces better quality images [27] [33] [35].

Also, we propose that the battery and memory capacity of the smartphones be considered as an important feature or property for assessment of CCIA devices in low-resource settings. The reason is that a higher battery capacity is essential to provide enough power during image acquisition and through the process of cervical cancer detection. This is important especially in areas where the power supply is short or absent. In respect to this, smartphones with Universal Serial Bus (USB) cable supports will ensure additional power supply when a power bank is connected to it.

Also, the USB slot will serve as a medium through which the images can be transferred to other devices such as a computer, external hard drive, or flash drive for storage.

We also propose that the memory capacity be considered as well. A higher memory capacity is essential to provide sufficient memory to store the images during the cervix image acquisition. Appendix-I lists the device models used by previous researchers and their specifications.

IV. SUMMARY OF LITERATURE

Table 2 summarizes the literature reviewed in this paper.

Table 2. Summary of Literatures

CCIA Device	Ref.	Comment
Digital camera on microscope/colposcope	[1] [10] [15] [11] [4] [17] [18] [20] [21] [22] [25] [12] [13] [9] [14]	High screening accuracies achieved. Sophisticated devices involved including CCD/ CMOS enabled digital cameras, microscopes, and colposcopes. Not feasible as a low-cost CCIA system.
Whole slide scanner/Imaging system	[23] [19] [24]	Not applicable in a VIA screening setting. Not feasible as a low-cost CCIA system.
Smartphone-based	[26] [28] [39] [27] [33] [31] [37] [39] [30] [34]	May or may not involve the use of microscopes and colposcopes. Lower screening accuracies achieved. Can be used during VIA screening exercises. Can standalone as a CCIA/classification device. Most feasible as a low-cost CCIA system.

V. DISCUSSION

From Appendix-I, all the devices have USB cable supports and used LED flashlights during the image acquisition. This emphasizes the importance of these features during cervical cancer screening. Considering the memory capacity as an important feature, the iPhones and other iOS devices (such as the Apple iPod touch) will not be considered as a low cost CCIA device because based on a checklist of the most important features identified, they have no provision for external memory. Also, the financial cost of developing an application on iOS, makes Android operating system-based devices a more suitable low-cost option.

Looking at the battery capacity, Samsung Galaxy S2 has the highest battery capacity with duration of 710 hours but with a low image resolution of 480x800 pixels and a low camera megapixel sensor of 8MP as compared to Sony Xperia, Samsung Galaxy Note 3, Samsung Galaxy S4, and Samsung Galaxy S5. A high battery capacity is very important in considering a low resource screening tool where power supply could be an issue. Yet, priority will be given to image resolution as there can be an alternative power supply. Hence, Comparing the 4 mentioned devices with the highest image resolutions, Sony Xperia has the highest battery capacity, but a lower camera and image resolution as compared to Samsung Galaxy S4 and Samsung Galaxy S5. Though the Samsung Galaxy S5 has the same image resolution as the Samsung Galaxy S4, the former has a higher camera definition of 16MP and a higher battery duration of 390 hours. Therefore, it has been deduced from this review that the Samsung Galaxy S5 will be more suitable as a low-cost CCIA device and screening tool for low resource settings.

Also, as we can see from Table 2, most of the research used colposcopes and microscope-based CCIA devices and a few used whole slide scanners and other related imaging systems. From the results obtained [1-44], both cases produced higher screening and classification accuracies than the smartphone-based CCIA devices. Yet, the smartphone-based devices are more feasible as low-cost screening devices due to ease of use and financial implications. As a result of this, there is a need for researches that focus on improving the accuracy of smartphone based cervical cancer screening tools.

VI. CONCLUSION AND FUTURE WORK

The lack of awareness and limited access to health services has created a need for researches aimed at extending the reach of cervical cancer screening to low resource settings. Being a deadly disease that is most prevalent in low resource settings, it requires a low-cost means of screening. The use of digital cameras and smartphones have been implored in low cost cervical cancer screening exercises. So far, the smartphone is the cheapest image acquisition tool that could be used during cervical cancer screening. Based on certain suitability properties that have been considered to be the most important factors for choosing a CCIA tool, the review proves that the Samsung galaxy S5 can be considered to be the most suitable cervical cancer image acquisition tool to be used during low-cost screening. It is hoped that other smartphones, especially more recent (current year) smartphones could be tested in cervical cancer image acquisition as future work. The ultimate aim is to replace the colposcope-based examination and the CMOS/CCD digital cameras (used in cervical cancer screening) with a smartphone-based one (low cost screening tool), thus extending Cervical cancer screening to those resource-constrained areas who have no access to a standard colposcope and who are likely to suffer the most from the consequence of reduced access to health care.

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Appendix-I: The device models and specifications.

Device Model	Display Resolution (Pixel)	Camera Sensors (MegaPixel)	Operating System (OS)	LED Enabled	Battery duration in hours(h)/ Capacity in milliamp Hour (mAh)	USB Cable Support	Internal Memory	External Memory Capacity
Samsung Galaxy S5 [26] [28]	1080x1920	16MP	Android OS	Yes	Up to 390hours	Yes	16/32GB, 2GB RAM	Up to 256GB
Samsung Galaxy Note 3 [39]	1080x1920	13MP	Android OS	Yes	Up to 420hours (3200mAh)	Yes	16/32/64GB, 3GB RAM	Up to 64GB
Samsung Galaxy S4 [27]	1080x1920	13MP	Android OS	Yes	Up to 370hours (2600mAh)	Yes	16/32/64GB, 2 RAM	Up to 64GB
Samsung Galaxy S3 [33]	720x1280	8MP	Android OS	Yes	Up to 590hours (2100mAh)	Yes	16/32/64GB, 1GB RAM	Up to 64GB
Sony Xperia [31]	720x1280	12MP	Android OS	Yes	Up to 450hours (1750mAh)	Yes	32GB, 1GB RAM	No
Motorola, Moto G, Second generation [37]	720x1280	8MP	Android OS	Yes	2070mAh	Yes	8GB, 1GB RAM	Up to 32GB
HTC, One X+ [39]	720x1280	8MP	Android OS	Yes	Up to 360hours (2100mAh)	Yes	32/64GB, 1GB RAM	No
iPhone 5s [30] [33]	640x1136	8MP	iOS	Yes	Up to 250hours (1560mAh)	Yes	16/32/64GB, 1GB RAM	No
Apple Ipod touch [31]	640x1136	8MP	iOS	Yes	1043mAh	Yes	128GB, 1GB RAM	No
iPhone 4s [27]	640x960	8MP	iOS	Yes	Up to 200hours (1432mAh)	Yes	8/16/32GB, 512MB RAM	No
Samsung Galaxy S2 [27]	480x800	8MP	Android OS	Yes	Up to 710hours (2100mAh)	Yes	16/32GB, 1GB RAM	Up to 32GB
Samsung SGH-U900 [34]	240x320	5MP	Android OS	Yes	Up to 407 (880mAh)	Yes	128MB	microSD dedicated slot
iPhone 4 [27] [33]	640x960	5MP	iOS	Yes	Up to 300hours (1420mAh)	Yes	8/16/32GB, 512MB RAM	No
Sony ericsson w900i [27]	240x320	2MP	Android OS	Yes	Up to 370hours (900mAh)	Yes	470MB	Up to 4GB