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Microscope and Mobile Phones: Product Development in Uganda

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Abstract: In this paper, we describe a design process aimed at improving medical diagnostics of rural areas of developing countries. Microscopy is a vital and omnipresent healthcare tool used in medical diagnostics and can be used for initial disease screening as well as for in-depth analysis of patient samples. However, microscopic analyses are considered laborious, time-consuming and most importantly, are dependent on the presence of well-trained personnel that can accurately establish a diagnosis on the basis of the microscopic images. As a result, medical diagnostics in developing countries have a poor reputation and often lead to misdiagnoses and wrongly treated diseases with far reaching consequences.

When combining the problems in medical diagnostics through microscopy together with the rising availability of mobile phones and growing coverage of rural areas with cellular networks, an interesting focus for improving access to specialized health care is found. Health workers with access to a microscope and a mobile phone equipped with a camera could be linked with a medical laboratory expert. Through this link health information could be exchanged, resulting in a more efficient and effective treatment of patients.

This paper explores the opportunities for such a system based on microscopy and the use of mobile phone cameras and presents insights in the user centred design process of a product linking microscope and mobile phones together with health practitioners in Uganda, so as to enable direct transmission of the images to experts to seek their advice.

Keywords: Health, Microscopy, ICT, Mobile phones, Diagnostic, Design, Uganda

1. Introduction

In developing countries microscopy is the most common investigation performed and it is a pre-requisite at all laboratory levels for control programmes of diseases such as malaria and tuberculosis [1]. Microscopes are also the most essential piece of equipment available in every health facility laboratory in resource-poor countries, even in remote areas [2].

However, laboratory services are one of the most neglected areas of health care provision in sub-Saharan Africa. The poor quality of microscopy services has long been recognized in practice and is a function of multiple factors, including staff shortages, training and skills maintenance, slide preparation techniques, workload, condition of the microscope, and quality of essential laboratory supplies [3][2][7].

As a result, inaccurate diagnosis, or misdiagnosis occur, and have reached alarming levels all over Africa [1]. It can lead to patient mismanagement (waste of public and

individuals' resources), misperceptions about resistance patterns and public health misinformation, which is of high importance for epidemic preparedness and intervention. They also generate a culture of mistrust, from patient towards health care, but also between laboratory and clinical staff. This contributes to communication breakdown and to low morale within the technical profession [5][6].

On the other hand, Africa and Uganda in particular have witnessed the emergence of a mobile revolution where mobile phones have become almost commodities. From 1999 through 2004, the number of mobile subscribers in Africa has jumped from 7.5 to 76.8 million, an average annual increase of 58 percent [4]. This has brought considerable development at the community level and sparked economic growth in many remote places in Africa.

In this paper, we describe how the emergence of cellular networks in Africa could be used to leverage microscopy in rural Africa especially Uganda by developing products linking microscopes to mobile phones.

The remainder of this article is structured as follows. Section 2 describes the problem definition that is going to be tackled in this paper. In Section 3, additional information is provided on comparable initiatives in the academic community and industry. Section 4 provides a picture of the local context in the health and ICT sectors in Uganda. The method followed in this project is described in Section 5, while design specifications and functional requirements are spelled out in Section 6. Finally, early results and findings are provided in Section 7.

2. Objectives and Problem Definition

Most people with infectious diseases live in rural areas in developing countries and are treated in local health clinics. Although these small clinics do not have many facilities, most of them are in possession of a microscope, which are utilised by laboratory technicians. The microscope users have limited education and basic knowledge on microscopy. The larger hospitals on the other hand have more specialized staff. Linking these two groups allowing diagnositic-relevant information exchange between them, may make a difference in rural health care.

The ability to capture images of signs or samples and to send those images for remote diagnosis could drastically reduce both cost and time of performing critical disease diagnosis (as well as providing early warning of outbreaks in poverty stricken regions).

Consequently, the goal of the product development, as described in this paper, is to design a working model to connect a mobile phone equipped with a camera to locally available microscopes in Uganda by means of a product we wish to refer to as a "universal connector", such that selected microscopic images can be transmitted to experts seeking their advice. The main diseases under scrutiny in this paper are Malaria and Tuberculosis.

Figure 1 shows the basic idea of the system. In this figure, there are two locations with a microscopist on each site. Microscopist (with limited knowledge and training) at location "A" has a sample, but wants verification on his or her diagnosis. By connecting the mobile phone with the microscope by means of the universal connector, an image of the sample can be sent to the specialist on location "B".

While the all system needs to be design, this paper focuses on the connector part between the microscope and the cell phone, and do not address the complete system (the location B part of the system), nor the issues related to the transmission of the picture.

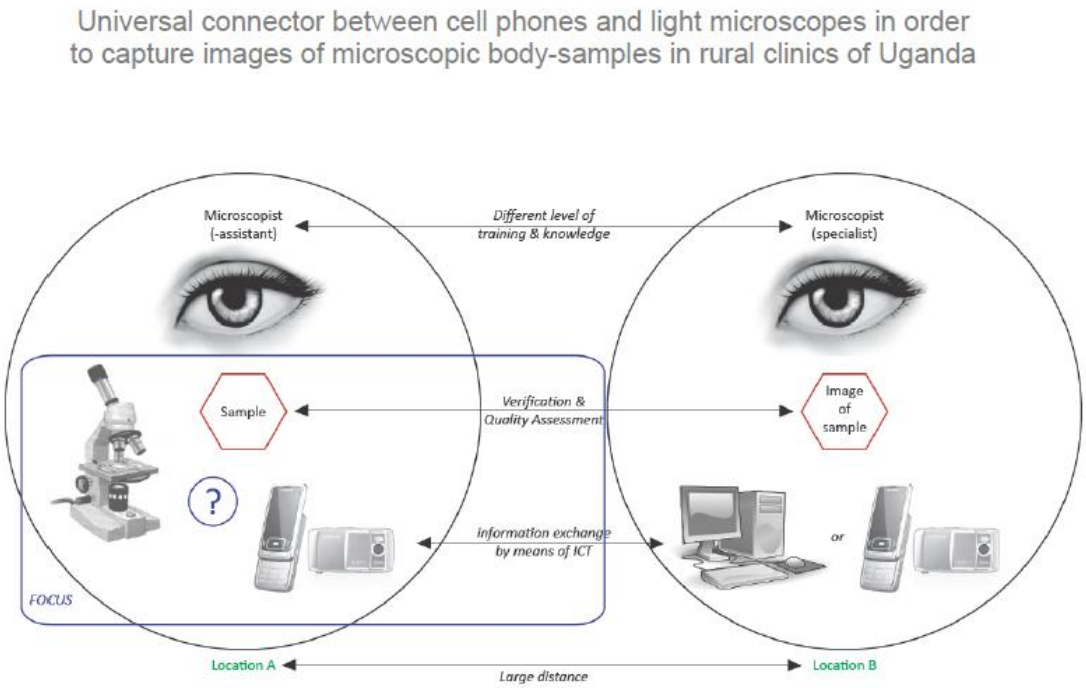

Figure 1: Microscopy and Mobile Phones Combination

3. Comparable Initiatives

For the past years various organizations [9][10][11] have been working on small and compact cameras which can capture high-quality microscopic images with resolutions from 1.3 up to 8 Megapixels. Most cameras have optical and digital zoom, and even provide a real time display for image previewing on desktop monitors or laptops (through firewire cable system or USB-connection). Images can be focused and positioned directly from a computer, and some microscope cameras can even be controlled with electronic shutters. As an extra feature there are cameras which are suitable for use on a microscope as well as for macro photography.

Most cameras used with microscopes have specially designed analysis software for various operating systems (Windows, Mac and Linux) allowing the user to capture and save images, view 3D models of 2D images, and transmit real time images across the Internet. Some of the most recent cameras have even sound recording up to one minute per image. All colour renderings, image geometry and dimensions are accurate to ensure accurate results are obtained during image analysis and image processing. These modern cameras are most suitable for image archiving, documentation, publication for the life sciences and many other industrial applications.

However, these are not suitable for the developing world as cameras need intervention of a personal computer for sending an image to another location by example. Although combined with a personal computer the cameras might form an integrated and powerful imaging system for microscopic applications, they are not universally applicable and are in most cases very expensive.

Closer to the needs of developing regions, researchers [8] at the University of California, Berkeley have developed a modular, high-magnification microscope attachment for mobile phones. The device will enable health workers in remote, rural areas to take high resolution images of a patient's blood cells using a mobile phone camera, and then transmit the images to experts at medical centres. The microscope has commercially available lenses

fitted inside a tube that snaps directly on the phone by a clamp. The other end has a clamp for holding a sample slide. With this solution different levels of magnification (5-50x) are possible. The product is in the field testing phase. Estimated sales price, if mass-produced, is less than $100.

In the product development described in the paper, only locally available products (e.g., mobile phones, microscopes) are used with an objective of designing a low cost system (complete price of the overall system to range from 15 to 20 Euros).

4. Local Context

4.1 Health

Health indicators in Uganda lag behind the rest of the world. Recent statistics show that life expectancy at birth in Uganda is around 53 years. Child mortality (death before the age of 5 years) decreased from 140 of every 1000 births in 2002 to 66 per 1000 live births in 2008. Total health expenditure as a percentage of GDP was 7.0% in 2005.

In 2004 there were 2209 physicians in Uganda, which means that there was less than 1 physician per 1,000 inhabitants. In the same year statistics show that nursing and midwifery personnel density was calculated as 7 per 1,000 of the population. (For comparison: in the Netherlands there are 37 physicians per 1.000 inhabitants (2005) and 146 nurses and midwives per 1,000 inhabitants (2006)). The number of laboratory health workers is 1702 (<1 per 1,000 population (2004)). Per 10,000 people there are 11 hospital beds available (2006); whereas in the Netherlands this number is 50 (2003) [12].

The health system in Uganda is based on a referral system, existing of different levels of health care, shown in an overview in table 1. Every inhabitant should be able to walk to the nearest Health Centre (H/C). In practice, the closest Health Centre is at level H/C II. The healthcare provider in charge of the Health Centre can refer the patient to a higher level and this can be continued until reaching the highest level (Table 1).

Table 1: Health Sector Organization in Uganda

Health provider	*Number*	*Description*
National Hospitals	2	National level (1 per 27,000,000 population) (in Kampala city)
Regional	12	Regional level (1 per 2,000,000 population)
District Hospital	90	District level (1 per 500,000 population)
Health Centre IV	154	County level (1 per 100,000 population)
Health Centre III	809	Sub-county level (1 per 20,000 population)
Health Centre II	1469	Parish level (1 per 5,000 population)
Health Center I	2500	Village Health Team (1 per 1,000 population)

The higher the level, the more facilities and expertise are available. The lower levels often lack human resources, equipment and basic facilities in general, like electric power and running water. Due to the poor reputations of lower level health providers patients often go directly to the district hospitals, leading to overloaded and congested hospitals.

4.2 ICT

ICT is emerging as an important medium for communication and exchange as well as a tool for development, including at the local and community levels.

Land line operators (Uganda Telecom and MTN Uganda line) offer a range of data services including ISDN, ADSL and local and international leased lines. Several Internet Service Providers are offering wireless broadband access. A new competition framework will liberalize VoIP Internet telephony completely, creating additional opportunities. The

introduction of UTL's Freenet service and a special national Internet tariff have helped to increase Internet usage.

Furthermore, the introduction of mobile telephony has revolutionized Uganda's telecommunications industry since the first network went live in 1995. As early as 1999 Uganda became the first country on the continent where the number of mobile subscribers passed the number of land line users, and the ratio is now more than 25:1. In 2007 there were 4,195,000 mobile customers against 162,300 land line customers and the market is constantly growing. Most of country is now covered by the cellular network coverage [14].

5. Co-Design and Methodology

A user centred design approach was adopted for development of the envisioned product: the universal connector for existing microscopes and mobile phones in the context of Ugandan health services. In a user centred design approach, the end-users are involved in each stage of the development process. Not only does this ensure an optimal end result for the specific contextual requirements, it also gives ownership of the design to the local users which is found to increase likelihood of adoption of the new technology into the existing workflow.

Via international NGOs (e.g., International Institute for Communication and Development (IICD)) and local stakeholders (Uganda Martyrs University), co-design meetings were set up with end-users of the envisioned product (local health practitioners) along with visits to various laboratories at local hospitals and health centres. The aim was to collect technical and non technical (human interaction) requirements for the universal connector in close co-operation with the local health practitioners. Additionally, various prototype models were also presented and tested with local health workers in rural clinics to serve this aim. This way, more insight could be gained of what systems would be understood best and whether changes would be needed to make the product more understandable, and at the end more desirable to use.

The targets of the field study can be summarized as follows:

- Context research
  - Verification of background information on health care situation in Uganda (rural – urban, hospital / clinic, current assessment programs)
  - Recording of environmental situation (infrastructure, facilities, amount of staff)
- Target group exploration
  - Gathering specific information on microscopy use in Uganda (number and level of microscopy for infectious diseases)
  - Gathering specific information on mobile phone use in Uganda (types of phones and used functionalities)
  - Study cultural based aspects which could impact the design of the product
- Co-design and test of prototypes

The methods used in the field trip include

- Observations for analysis and preparation for possible implementation
- Interviews with less and more experienced microscopists. Figure 2 shows the story board used to explain the concept of the product to the interview participants.
- Working session (user research) which can be divided into association research, prototype and colour study

This method follows closely the strategy of product development at the base of the pyramid [15].

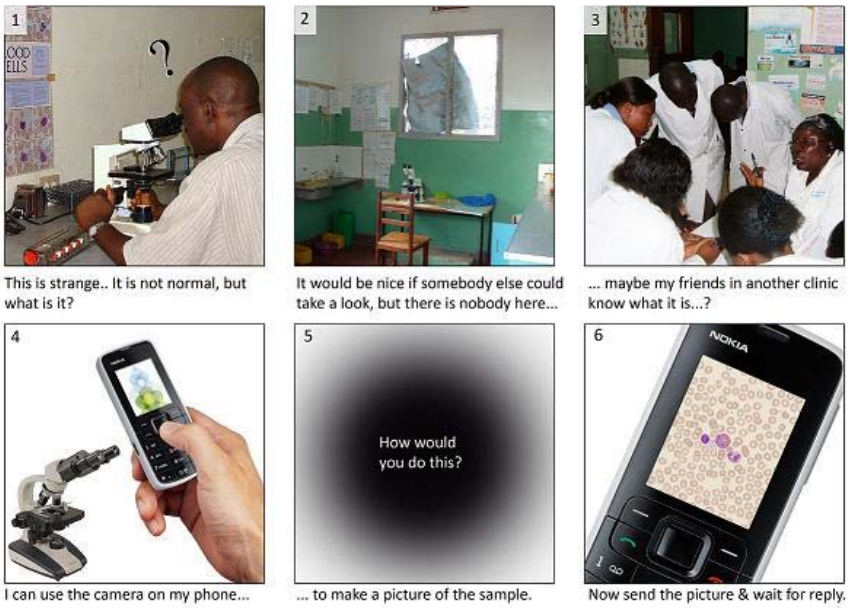

Figure 2: Story Board Used During Interviews

6. List of Requirements

A list of requirements was detailed out before the field trip and completed with information collected during the site visits. The following dimensions were considered:

- Performance
- Product criterion
- Environment
- Appearance
- Life span
- Maintenance
- Cost price
- Production
- Regulations
- Ergonomics
- Reliability
- Safety
- Liability
- Installation
- Disposal / recycling

While the list of requirements is too extensive to be reported completely in this paper, few examples are listed below:

- Product criterion
  - The light microscopes must have one or two oculars with outer tube diameter between 25 and 42,5 mm
  - The cell phone must be of bar-model with minimum dimensions: 94 x 42 x 6 mm (h x w x d) and maximum dimensions: 116 x 67 x 24 mm (h x w x d)
- Life span
  - The connector must have a life span of at least 10 years when used three times a day, six days a week (on average) and maintained monthly
- Production
  - It is desired that the product is producible within Africa

The list of requirements was then used in the design of the "universal connector".

7. Early Results

Visits to hospitals in Kisubi and Nkozi, Health Centre IV in Bojege, Health Centres III in Nakawuka, Buwama and Kasanje and Health Centres II in Nsagu and Kasenge and interviews with health workers at these locations bought valuable input to system design.

Figure 3: Nkozi Hospital Microscopy Unit

Not only did health workers find the project of interest but they also suggested additional usages of the system for education purpose or for improving the zooming capabilities of the microscope. They also shaped greatly the functional requirements described previously.

Health workers also participated in early system testing. Figure 1 shows two test samples taken with the camera of a Nokia 6233, locally available in Uganda. On both samples, health workers were able to recognize the disease to diagnose (on the left Malaria, on the right Tuberculosis). This exercise also helps the design team extract requirements for the design of a "universal" connector between the microscope and the cell phone.

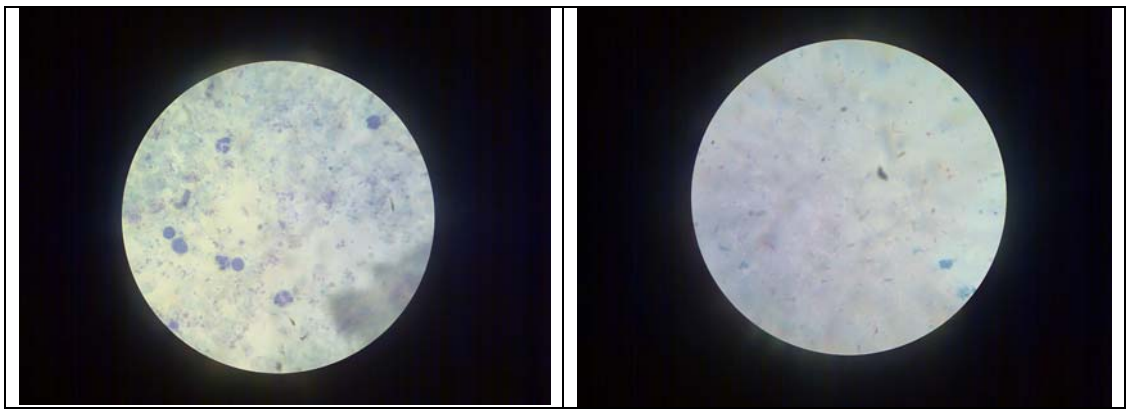

Figure 4: Test samples; Malaria (left), Turberculosis (right) taken with a Nokia 6233

The design team is currently building a working prototype of the connector.

8. Production and Beyond the Pilot

8.1 Who is Going to Finance the Camera Phones?

It may not be expected that the laboratory assistants in smaller health units would purchase such a phone by themselves, but there is a variety of options that is possible:

• Own purchase: camera phones are relatively expensive, and it does not provide direct benefits for the owner himself.

• Partly funded: the user feels responsible for the product when they also pay for it. There is a risk however that the phone will be sold again for a higher price than he paid.
• Micro-financing: there is an agreement so the owner can use the phone, and there is a penalty when the has an actual responsibility
• Fully funded (= donated)

8.2 Who is Going to Finance the Costs for SMS / MMS / Calls?

It is desired to have these costs funded or partially funded so that the laboratory staffs is not inhibited for having to pay for sending a message for information. Investigations are on-going to approach network providers to establish a balance between commercial interest and the community service offered by hospital in Uganda.

8.3 Deployment

An incremental deployment strategy has been selected to improve the design via continuous co-designing with end-users, small scale testing and finally large scale commercialization as described in the figure below.

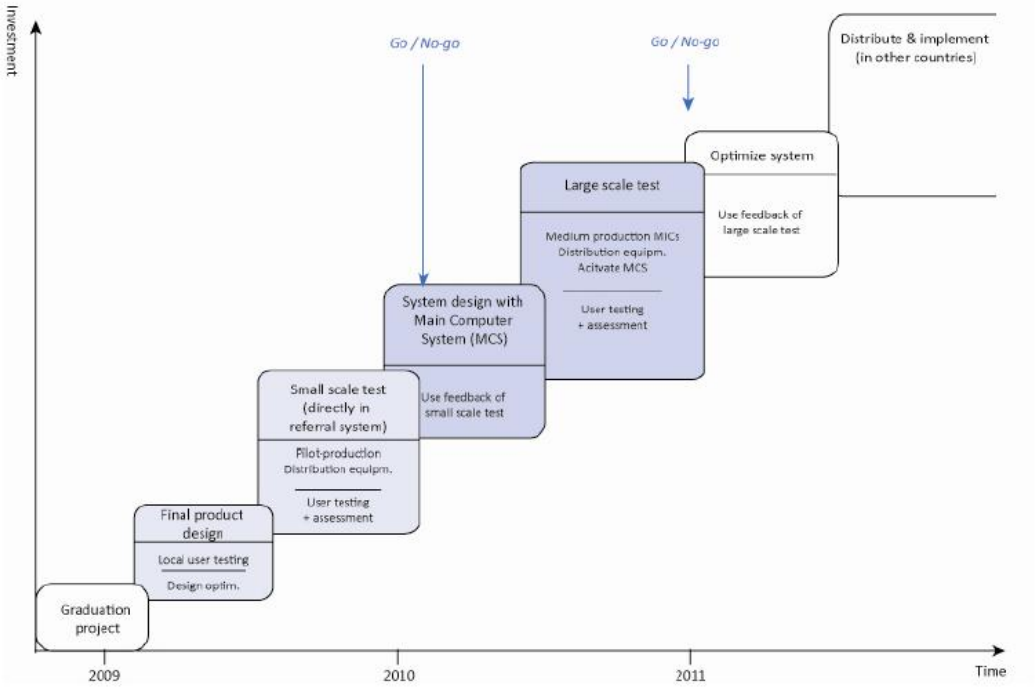

Figure 5 Deployment Strategy

9. Conclusion and Next Steps

In this paper, we have presented a design process aimed at improving medical diagnosis by connecting microscopes and mobile phones. The resulting solution uses mainly locally available products and does not requirement strong technical knowledge to operate it. The co-design of the product under development is made in close cooperation with health practitioners in Uganda to ensure the most useful and acceptable product.

The resulting system has the potential to reduce misdiagnosed diseases greatly and enabling information exchange among health workers. Further work includes finalizing the design of the "universal" connector and testing the working prototype in health centers in Uganda to ensure the soundness of the design of the system.

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