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A CONCEPT OF AN INTEGRATED SYSTEM FOR MONITORING CHANGES ON THE HUMAN SKIN

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Abstract

In this study, a concept of an integrated system for monitoring changes on the human skin is presented. The system is based on a static or mobile self-service front-end facility. Its purpose is to support an early detection of abnormal changes on the skin surface within a skin cancer prevention scheme, especially in the countries or areas where the public health care is not appropriate or widely available. Periodically performed skin self-examination is useful but subjective, and thus not reliable. To provide a more reliable method of skin examination, a design concept of a front-end facility is introduced. The facility can be a mobile booth that can be easily mounted in a public place with only few installation demands or it can be a permanent facility inside a building. It would be capable of making automatic video recordings or of taking photographs and, based on the given user ID, of comparing samples and detecting changes via a connection to the central monitoring system. Advantages of the system would be its accessibility for general public, unmanned operation, and a centralized database and detection system operated by medical experts.

Keywords: Industrial design, Large-scale engineering systems, Social responsibility, Vision systems, Skin cancer prevention

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1 INTRODUCTION

Skin is the largest human organ with an 18% share in the total mass of the human body. It is the first line of defence and a barrier between the body and the environment. Because of various influences and for different reasons, skin can develop a skin cancer which is by far the most common type of cancer in the USA. Among various types of skin cancer, malignant melanoma accounts for less than 2%, but causes a great majority of deaths (American Cancer Society, 2016). Globally, malignant melanoma is in the top 20 of most common cancer types (World Cancer Research Fund International, 2016). Depending on the source and the region of the World, the data vary: according to the Skin Cancer Foundation Statistics (2015), one in every five Americans will develop skin cancer in his/her lifetime; according to the Cancer Research UK (2016), malignant melanoma was the ninth most common cancer in Europe in 2012. Roebuck et al. (2015) determined that the skin cancer incidence was increasing at epidemic rates. According to GLOBOCAN 2012 (2017), the most critical situation among the 20 highest rates in 2012 was in the USA, with a total of 69,000 diagnosed cases and 10,100 fatalities (Figure 1a). At the same time, the risk of developing the disease or dying from it (expressed as the number of new born children, out of 100, who would be expected to develop/die from malignant melanoma before the age of 75) ranges between 1.2 and 4.4, and between 0.3 and 0.7 (Figure 1b), respectively.

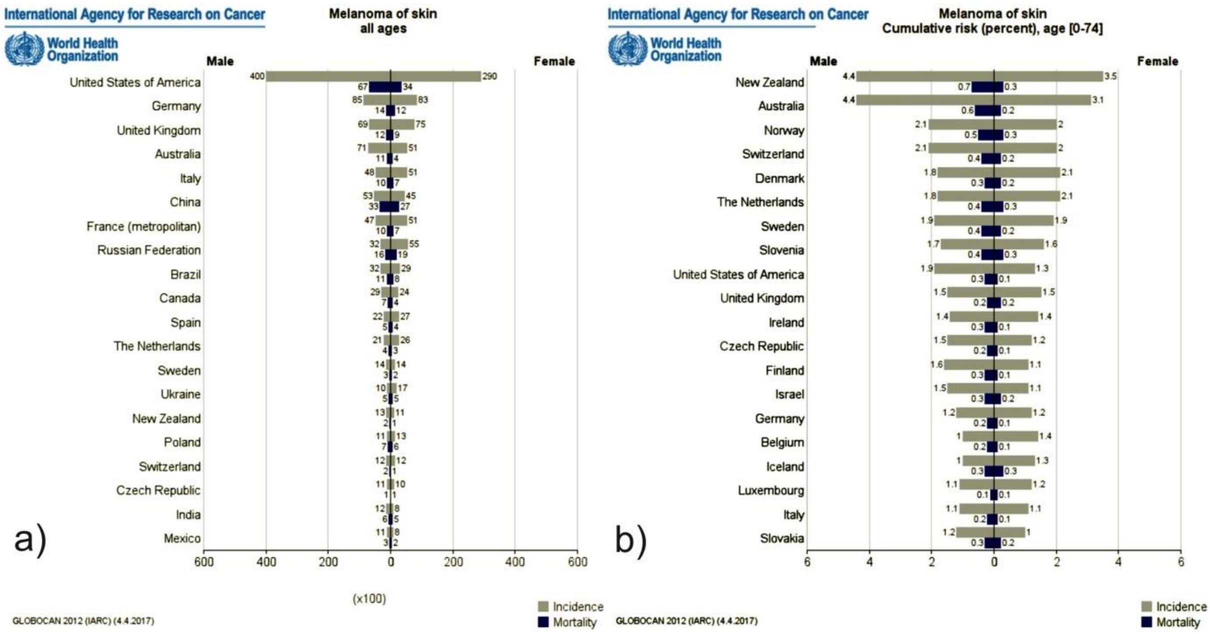

Figure 1. (a) 20 highest rates of malignant melanoma; (b) cumulative risk of malignant melanoma

What should concern even more are predictions for the period up to the year 2030 based on the current data and demographic change (GLOBOCAN 2012 (2016)), see Table 1. According to those predictions, the number of expected diagnosed malignant melanoma would rise by more than 51% and deaths by 58%.

Although not all melanomas can be prevented, certain actions could be performed to reduce the risk and provide an early detection. According to Roebuck et al., 2015, 98% of skin cancers are curable if diagnosed in an early stage, with survival rates decreasing to 15% if detected in later stages. That is why special attention is focused on self-examination as the first measure to prevent the spread of the disease. The aim of the skin self-examination is to perceive abnormal changes, odd moles, and various growths. As recommended by the American Cancer Society (2016), and probably by many other health organisations, self-examination should be conducted periodically, as often as once a month, including a detailed inspection of all body areas, especially the back where, about one of every three melanomas in men occurs. Self-examination could be quite a frustrating task because not all body areas can be easily seen and there is a quite intriguing state of mind involved when one is looking over the shoulder at the mirror reflection of his own back, wondering if there was a change or not.

Table 1. Estimated numbers of newly diagnosed malignant melanoma and deaths

		Estimated number of new cancers (all ages)			Estimated number of cancer deaths (all ages)		
Year	Age	Male	Female	Both sexes	Male	Female	Both sexes
2012		120,649	111,481	232,130	31,390	24,098	55,488
	ages < 65	62,066	66,342	128,408	13,750	10,473	24,223
	ages >= 65	58,583	45,139	103,722	17,640	13,625	31,265
2020		147,721	132,262	279,983	38,745	29,064	67,809
	ages < 65	71,893	75,399	147,292	16,083	12,105	28,188
	ages >= 65	75,828	56,863	132,691	22,662	16,959	39,621
2025		167,053	146,827	313,880	44,232	32,837	77,069
	ages < 65	77,759	80,621	158,380	17,495	13,067	30,562
	ages >= 65	89,294	66,206	155,500	26,737	19,770	46,507
2030		188,495	162,901	351,396	50,489	37,236	87,725
	ages < 65	82,902	85,176	168,078	18,708	13,879	32,587
	ages >= 65	105,593	77,725	183,318	31,781	23,357	55,138

1.1 Current prevention procedures and options

Prevention procedures recommended by various health organisations and societies encourage people to conduct periodical self-examinations. A detailed description of signs and symptoms of melanoma skin cancer can be found on the web page of the American Cancer Society. As stated there, a new spot on the skin that is changing in size, shape, or colour, or looks different from all other spots on the skin, should be treated as a warning sign and checked by a physician. There is also the ABCDE rule as a guide for the self-detection of the usual signs of melanoma:

- A - Asymmetry of a mole.
- B - Border of a mole which is irregular, notched, or blurred.
- C - Colour which is unevenly distributed and which may include variations of brown and black, or even be patched with pink, red, white, or blue.
- D - Diameter of a mole, if larger than 6 mm; note that spots of less than 6 mm in diameter can be diagnosed as melanomas if they have other characteristics listed here.
- E – Evolving; if the above-mentioned characteristics of the mole are changing.

There are some additional signs that can be used because not all melanomas follow these rules:

- A sore that does not heal.
- Pigment spreading from the border into surrounding skin.
- Redness beyond the border.
- Strange sensation, such as pain or itchiness.
- Surface change.

The bottom line is that any anomaly observed in self-examination should be reported to a physician. However, according to a study conducted among various specialists from a professional state organisation (Roebuck et al., 2015), there are barriers to performing melanoma assessments. The most common barriers reported were: time limit, limited access to dermoscopy, inappropriateness of the setting, and inadequate skills. Although each of these barriers could be discussed individually, only one of them will be emphasized here by referencing the data collected from the Croatian Health Insurance Fund (Hrvatski zavod za zdravstveno osiguranje - HZZO, 2015 and 2016) (Table 2).

Table 2. Number of scheduled examinations and average waiting time before the examination by a dermatologist (HZZO, Croatia)

	Data on 19 October 2015		Data on 02 October 2016	
	Scheduled examinations	Average period of waiting /days	Scheduled exams	Average period of waiting/days
Dermatology – first exam	4,678	48	5,329	57
Dermatology – oncology	359	90	302	79

As it may be seen, in a period a bit shorter than a year, the average waiting time for the first examination rose by 9 days and for the oncology examination fell by 11 days. At the same time, the number of scheduled first examination (of unknown medical conditions) rose by 651, while the number of oncology examinations (for diagnosed medical conditions) fell by 57. These numbers do not show much because the number of available dermatologists is not included; therefore, it is impossible to estimate the number of scheduled examinations per specialist. Nevertheless, these numbers clearly show the trend.
Obviously, people should participate more actively in the process of prevention and early detection of the disease; however, this might not be as simple or straightforward as it seems.

1.2 State of the Art

Considering the importance of early detection, the growing trend of the disease incidence, its seriousness and rapidly rising mortality, it is not surprising that a number of systems to support the prevention part of health care have been developed worldwide in the past two decades. They are based on different technologies, and undoubtedly present the state of the art in the scanning of human skin for melanoma and/or other skin diseases. Based on the scanning area size, scanners can be roughly divided into two major groups: single point or small area scanners and whole body scanners. Each system comprises hardware and software, bought from the market or custom-developed and built.
For example, in the single point scanner group, one can find the Infrared Scanning System developed by researchers at the Johns Hopkins University, Baltimore, MD, USA, the Verisante Aura, which uses Raman spectroscopy at the molecular level, developed by researchers at the BC Cancer Agency, Vancouver, BC, Canada, and the VivoSight, based on the infrared multi-beam Optical Coherence Tomography (OCT), developed by Michelson Diagnostics Ltd, Maidstone, Kent, UK. These devices are to be used by experts. The first two systems are intended for one time detection. They do not have a digital image history recording capability (or such a capability is not mentioned), while the third one has. It should be pointed out that there are many other systems intended for the same purpose.
In the full body scanner group, there are fewer examples. There is a full body dermatological scanner developed by researchers at the Fraunhofer Institute for Factory Operation and Automation IFF, Munich, Germany, at the initiative of and in cooperation with the University Clinic for Dermatology and Venerology in Magdeburg and the partners (Dornheim Medical Images GmbH and Hasomed GmbH) (news released in May 2015). This stationary system combines both 2D and 3D data from calibrated cameras and 3D sensors in order to define the spatial position of each pixel, making the process insensitive to a change in the scanning distance and preserving relative distances between pixels. The next one is the FotoFinder dermoscope, developed by FotoFinder Systems, Inc., Columbia, MD, USA, which is probably the most widely used system. This is, in fact, a full family of products which offers a hand-held scanner (Dermoscope Portable), a full body scanner (Dermoscope Studio) and a smart mobile application interface (Handyscope). The first two devices use optical, high quality, high density cameras. The Dermoscope Studio has some automatic features and parallel image display capability with simultaneous zooming for the ease of comparison between old and new images. The Handyscope is additionally supported by the FotoFinder Hub, a cloud platform which offers an online storage centre for photos taken with Handyscope. The last product in this family of products is the FotoFinder Bodystudio ATBM, which was introduced to the market in September 2015. According to its developers, Bodystudio ATBM is the first automated skin cancer screening system of its kind, which includes all the parts needed for the user self-service. For example, it is suitable for being used in companies with a large number of employees.
At the end, a word or two has to be said about the use of smart phones. They offer a variety of applications to general public. Punching in the words *skin scanner* to any Web search engine will most probably result in some phone-based, free-to-download scanner application with a variety of options. Do not take me wrong, it is a great thing that such applications exist - they provide the potential for analysis and long term monitoring of selected moles. However, the use of such applications is based on self-discipline. In addition, smart phones come with some hardware shortcomings (e.g. the camera and illumination depend on the price), and their application directly depends on the number of moles. If there is one suspicious mole on the skin, and if it can be easily reached for taking a clear photograph, such an application can be very useful and potentially life-saving. But, it becomes useless if the skin is packed with a number of moles, especially on the back (Figure 2). A wider angle camera focus is not applicable, while taking shots one by one may sound like an impossible mission, at least for the user

himself in this particular example. Of course, self-examination is still mandatory in order to spot some changes which should subsequently be photographed and sent for the analysis.

Figure 2. Number of moles across the human skin

1.3 The goal

Full body scanner systems of various capabilities are already available on the market; they are intended for use in urban areas, where they are operated by an expert, preferably by a dermatologist. These systems, most delicate in design, often come with a price, which small, economically modest communities cannot afford. Furthermore, these systems have to be guarded. In each of the considered systems it is expected from a patient to assume more than one position for scanning. On the other hand, there is no systematic plan of interconnecting individual units in order to create a wider, perhaps even a national network capable of storing, analysing, and comparing large amounts of data that can be extracted from digital images and used to broaden the knowledge in the field of skin diseases. It is the aim of this study to formulate a concept of a system which would meet most of the demands that the current systems do not.

2 A CONCEPT OF AN INTEGRTED SYSTEM FOR MONITORING CHANGES ON THE HUMAN SKIN

Although systems for total body photography or mole mapping exist, in most cases they are placed in national health institutions, specialized laboratories, and private institutions. This fact entails the previously mentioned problems of waiting time and available money. The idea of an integrated system for monitoring changes on the human skin based on a static or mobile self-service front-end facility was promoted in the autumn of 2012 in the bachelor degree thesis *Self-service based device for monitoring changes on the human skin* at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia. The main goal was to develop or start the development of a mobile front-end facility that could be operational, wherever placed, if some fundamental requirements are fulfilled. In this way, a high quality, accurate detection system would be available to the general population and could play a major role in the national health plan regarding the melanoma prevention. Although the concept was in its very early phase in 2012 (Figure 3), work on the idea has continued in order to produce an integrated system with the same purpose as the system generally described later by Jukic et al. (2013).

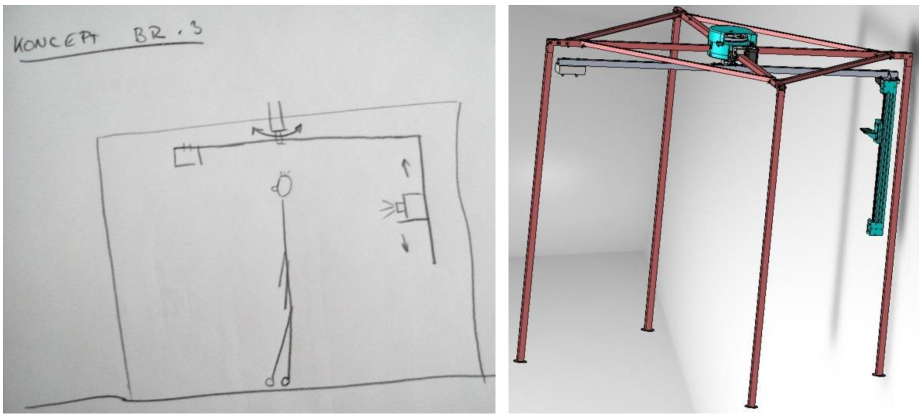

Figure 3. One of the early scanner concepts (left) and a design solution (right)

2.1 A concept of an integrated system

The system integrates all the parties involved: end user, national health centre or private health organisation(s), educational institutions, general physician (GP) or dermatologist (Figure 4). The system can be shared among various organisations, based on given credentials. In fact, since the system is based on computers and computer network and their rules, any usage scheme could be applied. Among the benefits of such a system is the integration itself because data can easily flow between authorized parties and all the data can be easily found. In addition, the system allows long-term monitoring, and data analysis and comparison on the national or even international levels.

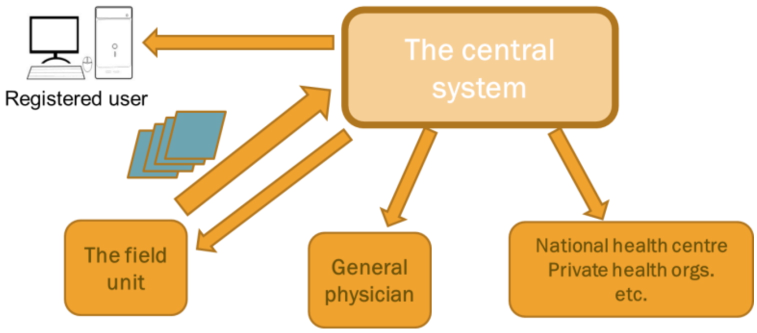

Figure 4. Schematics of the integrated system

The central system consists of three main parts (Figure 5):

- Main programme unit, responsible for all the necessary functionalities besides exclusively medical matters.
- Detection module, responsible for data analysis, medical alarm triggering, starting of new sample storage process, etc. Together with field units, which are intended for local data acquisition and processing, this is the most critical part of the system, designed, maintained, and updated under the supervision of dermatologists.
- Database, responsible for the storage of samples, user data, analysis results, etc.

The part of the system exposed to the end users is the field unit, the Self-Operated Skin Scanner (SOSS). The individual SOSS unit can be put into any appropriate type of a container; it can be stationary or movable. It is equipped with appropriate communication devices (Wi-Fi, hard wire or GSM) in order to integrate into the global system and make contact with the central system.

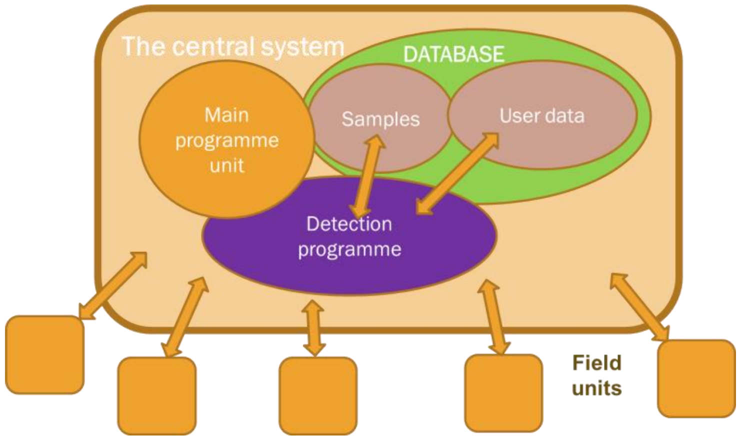

Figure 5. Schematics of the central system

2.2 Self-Operated Skin Scanner - SOSS

There are several requirements that a SOSS must/should meet to achieve its purpose in the integrated system:

- The unit has to be compact and adapted for easy transportation and handling.
- It has to be semi-automated and ready for unmanned operation.
- It should have an air-conditioned environment.

- It must have adequate protection systems, both for the unit itself and for the user data.
- It must have high quality light sources and photography equipment.
- It must be capable of communication by means of various models.
- Preferably, it should be adapted for senior users.
- Preferably, it should allow both voice control and video guidance in a local language, etc.
- It should be user-friendly and easy to operate.
- It should have a certain degree of autonomy regarding the energy source, but, preferably, it should use an external power supply.
- It must allow remote control operation or assistance.

In order to perform as expected, the SOSS is divided into several major subsystems according to their functions. Each subsystem is responsible for its domain, fulfilling one or more previously mentioned requirements. These subsystems are as follows:

- Authorization and authentication – checks user credentials; checks the network access and connection with the main or the regional server.
- Security – checks locks and doors on the SOSS unit, key cards or other types of cards used by the system; performs video monitoring and movement indication; alerts the authority when the system is misused; forces the system lock down in case of emergency.
- User guidance - enables interaction with the user via various interfaces, voice control and video guidance.
- Signals and alerts – consist of two parts: the first part displays various pieces of information to the user, such as what is expected from him/her or which part of the system is active; the second part alerts the user when some action needs attention or when the system has encountered some problems.
- Image capturing – controls the movement and operation of cameras and point targeting operation; ensures adequate lighting for the capturing process; checks lenses and ensures that they are clean. Depending on the design of the stand platform, this subsystem may control the movement of the platform as well.
- Data processing – processes captured images; encrypts the data and prepares it for sending.
  - This subsystem consists of several applications with specific tasks. The main application processes the data received from the image capturing subsystem and checks whether every image is in line with the defined rules. The image that is cleared in the previous application is compressed and encrypted so that it cannot be read by unauthorized parties. The prepared data (encrypted) is sent to the communication subsystem to be forwarded to the main server.
- Communication and control – establishes communication with the main server using the available connection (GSM, Wi-Fi, wired); shields the system from malicious intrusions (firewall); controls the whole system; maintains updates to other subsystems; enables communication among subsystems; enables remote operation and assistance.
- Environment – controls the temperature in the SOSS; controls the power supply and the backup battery status.
- Container – encapsulates all other subsystems in a physical casing.

Due to the complexity of such a system it is very likely that all the subsystems are not listed, although the listed ones should be sufficient to allow normal operation.

3 TECHNICAL FEASIBILITY

Most of the above mentioned subsystems can be easily built with standard mechanical and electronic components, and by utilizing computer hardware and software modules which already exist. With those subsystems, the problem is about the layout and integration rather than the development. Some of the subsystems are specific and have to be built from scratch.

3.1 The integrated system

The integrated system is no different than any other distributed system which involves users gathered around a central system. Means of communication between the system and the users may be any existing global wired or wireless network available. The central system collects and distributes data among the accredited users, being at their disposal 24/7. The accredited users are humans/machines who/which are properly registered and introduced into the system, having a certain level of clearance and some rights.

3.2 The central system

The central system is the heart of the integrated monitoring system. It consists of the general purpose and the specialized, custom-built computer software installed, preferably, in a localized network of computers. It would be desirable if the system was located near or in a national health centre. Part of the software which should be developed is the detection module which has to be available at the central unit as well as at the field units. The purpose of the module is to analyse digital images in order to detect malignant melanoma or other medical skin conditions. The module has to be designed in a way that allows the implementation of any available verified method for that purpose, as reported by Jukic et al. (2013), Godoya et al. (2015), and Li et al. (2016). In addition, the module has to be capable of comparing images of the same subject in order to determine possible changes, perform various crossover analyses, and interlink the data, potentially. This module has to be built under the supervision of dermatologists and other experts involved in melanoma detection and research into skin diseases.

3.3 The SOSS

SOSS unit is the data acquiring part of the integrated monitoring system. For the purpose of transportation, the unit can be put into a customized standard container of an appropriate size (for example, 1CC, L = 6,100 mm, B = 2,440 mm, H = 2,590 mm). This type of a robust housing protects the sophisticated equipment from the environment and provides enough space for adaptation and equipment layout. Most of the equipment has to be laid out in the end part of the container, which can be approached through a service opening or a door. The rest of the container space can be used as a preparation area and as a functional area. The functional area is the most important part of the container space where the scanning process takes place. Scanning may be performed with a static user and a camera located on a holder rotating around the user (Figure 3), or with a static user and several cameras, or with a rotating user stand and a static camera(s) (Figure 6).

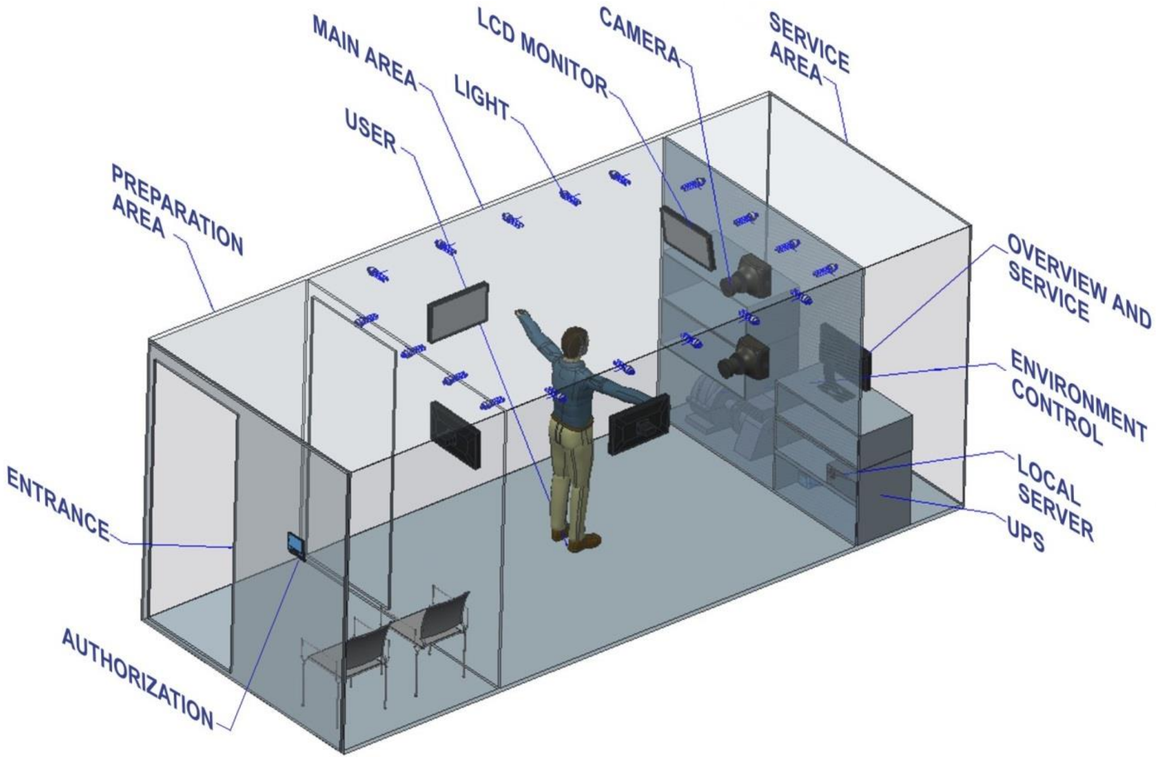

Figure 6. Design layout of the SOSS unit

The first solution is better from the aspect of a static user, and the second is better because there are no moving parts except for the rotating stand on which the user is standing during the scanning process.

Regardless of the design solutions of the scanning process itself, the functional area has to have adequate illumination with a capability of changing the intensity, the type, and the temperature of the light. The rest of the equipment consists of standard commercial parts which should be laid out according to their functions. A possible design layout in the container is shown in Figure 6.

3.3.1 Use-case scenarios

The utilization of the SOSS should be straightforward, as much as possible, from the authorization phase all the way to the image capturing procedure or scanning. Because of the trends in operating modern electronic equipment and the design of user interfaces (ATM machines, voice controlled phones and computers, etc.), perhaps the most effective way of operating the system would be by use-case scenarios. An authorization scenario is shown in Figure 7 as an example. The user introduces his personal identification card (health insurance card or any other card previously defined in the system) to the authorization interface. In the case of the card being rejected at the local authorization level, the authorization subsystem connects to the main authorization server in order to check the user credentials. If the user is registered in the main or regional database, clearance is sent back to the subsystem allowing access to the SOSS.

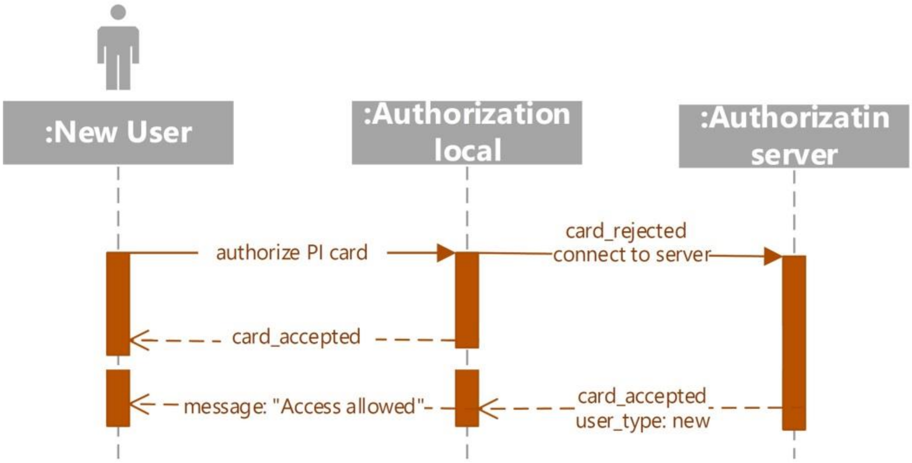

Figure 7. Use-case scenario of the authorization procedure

4 CONCLUSION AND FUTURE WORK

Although self-examination is recommended by many national health organizations as the first line of defence in melanoma prevention, it is not reliable in the long term. Expert systems, involving dermatologists, are not available for large population in a relatively short period of time and are mainly concentrated in urban areas. Dermatologists are not available in remote rural parts of the country and in less developed regions or countries. Optional, smart phone-based scanner applications can be useful but they do not provide uniform conditions and are not suitable for every body part or for systematic monitoring of larger skin areas.

A concept of an integrated monitoring system, including a Self-Operated Skin Scanner unit (SOSS) is introduced as an alternative. In our opinion, the system would be capable of providing the following benefits:

- Integrated monitoring system handled by dermatologists offers automatic or assisted detection at a distance.
- The system can be updated with the new knowledge including new samples for comparison, new data analysis methods, new hardware (cameras, lights), etc.
- The system is capable of long-term monitoring and of providing comparison capabilities.
- The system can be integrated into the national health plan and prevention and become widely available.
- Mobility and robustness of the SOSS units can be used to periodically cover distant areas.
- The SOSS units can be designed to support full self-service scanning without the need for a patient to assume more than one position.
- Both the users and their GPs can get access to the results (history and analyses).

Despite all the benefits mentioned above, the system should not be considered as a replacement for the examination by a dermatologist.

As shown in the brief technical feasibility overview, the integrated monitoring system can be created and brought to life. It is not the question of *how* to do it but rather the question of *funding*. The plan for future work is to conduct an opinion survey on the readiness of using such a system and to gather more data about the medical practice regarding melanoma issues.

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