Handheld 3D Scanning System for In-Vivo Imaging of Skin Cancer

Miguel ARES[*], Santiago ROYO, Meritxell VILASECA,
Jorge A. HERRERA, Xana DELPUEYO, Ferran SANABRIA
CD6 UPC Barcelona Tech, Terrassa (Barcelona), Spain

Abstract

We present a handheld scanning system for measuring in-vivo the 3D topography of the human skin surface. The system has been envisaged for analyzing the 3D shape of skin cancer lesions, providing a more precise characterization of the lesions compared with the conventional examination done by using the naked eye and dermoscopy methods. The 3D scanning system is composed of cost-effective and commercially available components, including two monochrome cameras placed in a stereo configuration, a color camera, and a compact projector unit. The 3D measuring principle is based on the technique of stereovision combined with the projection of structured light patterns. A first scanning prototype has been recently developed for imaging skin surface areas of 19 x 14 mm^2. A graphical user interface (GUI) has been also implemented to operate with the prototype. Preliminary experimental results showing the performance of this initial prototype for imaging different skin surface zones are also presented.

Keywords: Structured light scanning, stereovision, in-vivo 3D imaging, skin imaging, skin cancer

1. Introduction

The use of contactless 3D scanning systems for imaging the human body morphology has become of great interest in many different applications. In particular, multiple medical applications have found in 3D scanning technologies a way for going beyond traditional capabilities, such as 3D intraoral measurements of human teeth compared to the traditional physical dental impressions [1,2], characterization of scoliosis disease in 3D [3], 3D shape measurement of pectus excavatum deformity [4], or 3D digitization of the patient's face for aiding the surgical planning [5].

One of the medical fields where the 3D technologies are envisaged to play a significant role is in dermatology for assisting the clinicians in order to improve the diagnosis and prognosis of skin cancer lesions [6,7]. This is a relevant field of research where also some other optical technologies as for example multispectral imaging, optical feedback interferometry and reflectance confocal microscopy are under study with the aim of providing a better and early detection of skin cancer with respect to conventional approaches [8]. Nowadays, the naked eye and dermoscopy are the gold standard methods used for the examination of skin cancer, but they still fail in the correct discrimination of lesions in a significant percentage of the cases. The inspections based the diagnosis in the so-called ABCD rule, i.e. asymmetry of lesion shape, border irregularity, color variegation and lesion diameter. Thus, three of these four parameters (A, B and D) are related to morphological characteristics of the lesion surface. But they are associated with the two-dimensional (2D) features which account for a more limited information than in reality, as far as the skin lesions have a real 3D shape. Hence, the capability of measuring in-vivo the 3D topography of the skin cancer lesion by means of non-contact 3D scanning techniques, opens the possibility of a more complete analysis of the morphological features of the lesion with the final goal of providing better indicators for improving the identification of malignant skin lesions.

Although there is a wide range of different technologies with a proven success for 3D body scanning, three of the mostly used are those based in photogrammetry, laser scanning and structured light projection. Photogrammetry enables the reconstruction of the 3D shape from a minimum of two single images (stereophotogrammetry) taken from different views. The main benefits are the simplicity and the very reduced cost of the setup, but typically at a price of a higher computational effort and a worse accuracy of measurement. As opposed to this passive technique, both the laser profilometry and the structured light projection use a light source (i.e. active) and share the same measurement principle based on 3D triangulation from the deformation of the projected light over the surface to be measured.

[*] miguel.ares@oo.upc.edu; +34937398961; www.cd6.upc.edu

The most significant difference between the two techniques is the way in which the light is projected for scanning the object, being a single point or laser line which should be moved mechanically along the object in the method of laser scanning, whereas for the other technique a structured light pattern is projected in full-field over the object surface, yielding a significant reduction of the acquisition time.

In this work we present a handheld 3D scanner prototype based on a combination of two of the abovementioned technologies which are stereophotogrammetry (also called stereovision) and structured light projection. The compact unit is built with commercially available cost-effective components, meeting our requirements of a relatively reduced price and a quick response in the eventual case of damage due to the rapid availability of the components in the market. Besides the hardware part, a dedicated graphical user interface (GUI) has been also custom-built to fully control the prototype by operators like dermatologists and assistant nurses within a real clinical setting.

The paper is organized in three sections: in section 2 the first 3D scanner prototype developed is presented. Section 3 shows some preliminary 3D measurements of different human skin parts obtained in-vivo with the scanner. Finally, section 4 briefly summarizes the conclusions and future work.

2. The 3D scanning system

2.1. Hardware

The 3D scanner prototype developed has a compact design with a size of 220 x 240 x 120 mm. The prototype consists of a pair of megapixel monochrome cameras placed in a standard stereo geometry, a light picoprojector placed in the middle of the cameras, and a color camera also positioned between the two stereo cameras. All the cameras have an optical fixed focal lens (25 mm) designed for imaging a 19 x 14 mm^2 field of view (FOV) of the skin surface at a working distance of 110 mm. A personal computer (PC) is also incorporated for controlling the system, including the control of the light picoprojector through USB 2.0 connection, the stereo cameras through USB 3.0 ports and the color camera through USB 2.0. All these components are integrated into a rectangular black housing for minimizing the effects of light reflections inside. Figure 1 shows the first version of the prototype already built.
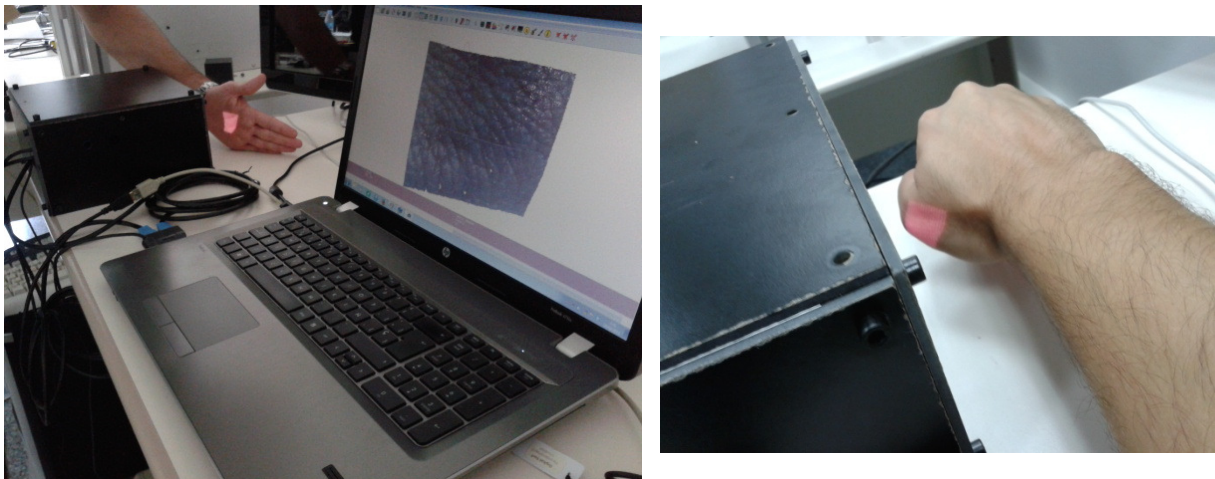

Fig. 1. First version of the handheld 3D scanner prototype built. Live measurement of human skin is shown in the images.

2.2. Method

The measuring principle of our 3D scanner is based on the well-known techniques of stereovision combined with the projection of fringe patterns. The light picoprojector sequentially projects a set of sinusoidal patterns shifted over the skin. For each projected pattern the two stereo cameras capture the images in a synchronized way. Once the procedure of fringe projection and acquisition has finished, the skin is finally illuminated with a uniform field from the projector and the image captured with the color camera. The recorded fringe images are then processed by a conventional phase-shifting algorithm to obtain the wrapped phase maps for both cameras [9]. Afterwards, the phase maps are

unwrapped based on the well-known Goldstein algorithm which has been chosen in our case due to its good balance between a fast processing time and a good quality of performance [10]. Finally, the corresponding phases between both cameras are identified and then the 3D data is obtained by triangulation based on the epipolar geometry and the system's calibration parameters previously computed. Additionally to the geometric coordinates of the object points (X, Y, Z) the color information of the skin texture (R, G, B) is superimposed. This is possible due to the calibration process performed for the three cameras involved. Figure 2 shows schematically the abovementioned measurement procedure.
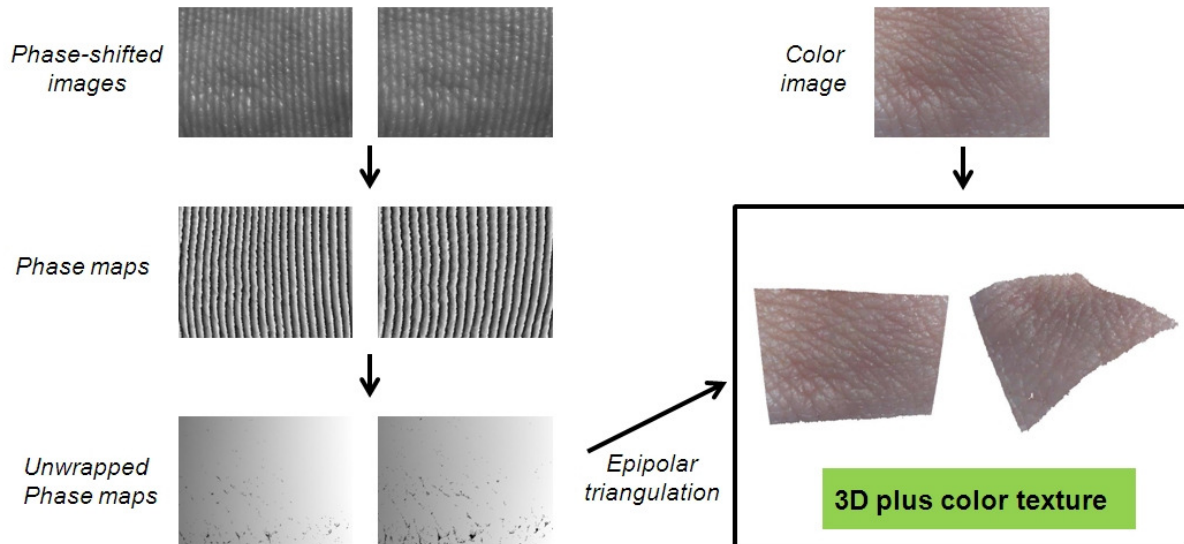

Fig. 2. Scheme of the measurement procedure that follows the 3D scanner prototype for getting the 3D data with the color texture superimposed of the skin surface.

In our case, the calibration of the scanner is performed using the technique proposed by Tsai [11] with a calibration rigid object wearing a black and white checkerboard pattern as shown in the figure 3. The 2D centroids (i, j) of the intersection of the checkerboard squares are computed for each of the cameras. As far as real 3D world coordinates (X, Y, Z) of the checkerboard points are known, the calibration parameters are thus obtained by solving the equations that account for the correspondences between the 3D points in the scene and the 2D points in the images, according to Tsai method.
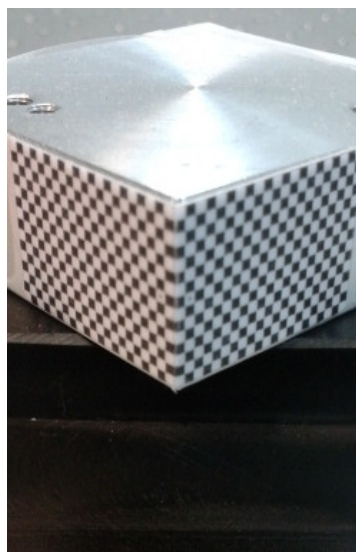

Fig. 3. Calibration object with a checkerboard pattern printed for computing the calibration parameters of the system.

2.3. GUI

In addition to the hardware part of the 3D scanner prototype already described, a GUI in C++ code has been also custom-built for controlling the scanner in a clinical examination room by operators like dermatologists and assistant nurses who obviously do not have an engineering technical profile. The GUI allows the operator to work with the device in a friendly and easy way, with the procedures of calibration and 3D measurement fully automated. The GUI visualizes in live mode the images shown by the cameras to assist the operator to correctly select the skin area to be measured. It also allows the control of the light intensity in order to avoid under or overexposure of the images depending on the reflectance characteristics of the patient's skin (i.e. white skin, black skin, etc.). Both the automatic calibration and 3D measurement process of the scanner are also executed through this user interface. The GUI also provides a basic form to input some clinical data of interest like the patient identifier (Patient ID), the type of lesion analyzed (Lesion), the date of measurement (Date), the number of measurement (#Measurement) and the name of the digital file in which the 3D cloud of points plus the color texture will be stored. The main screen of this basic GUI is presented in figure 4, where a crumpled paper with a text and rectangles of different colors is imaged as an example.
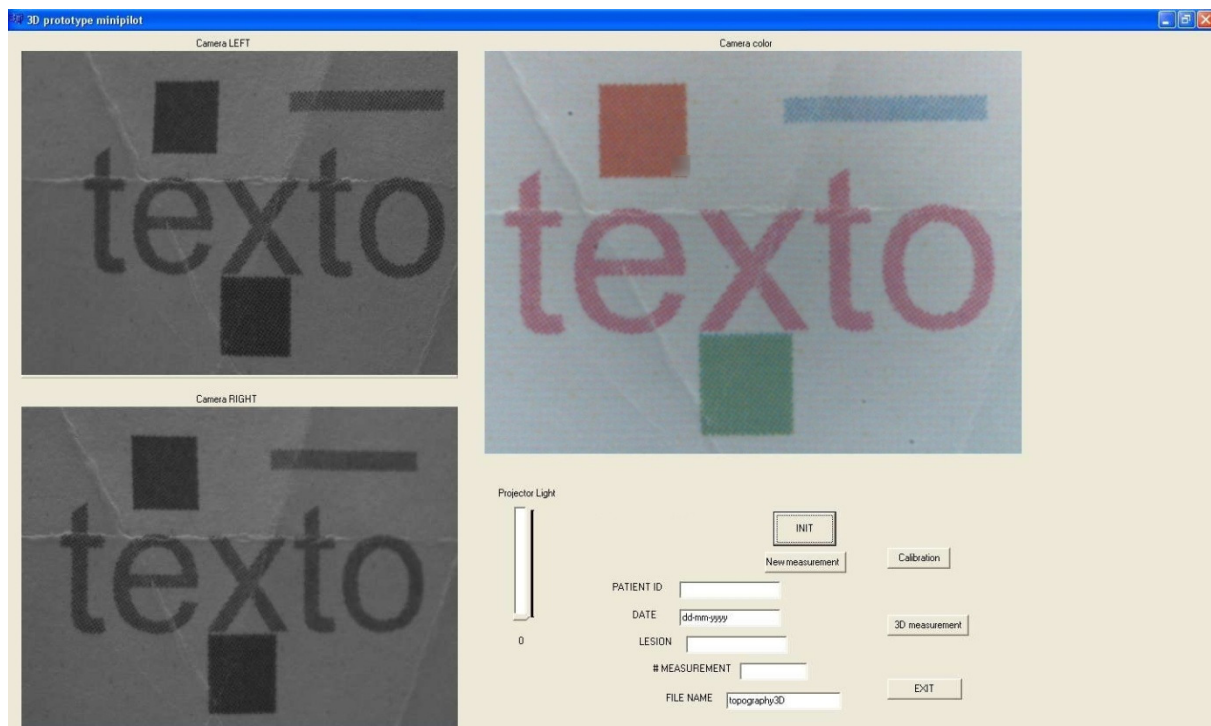

Fig. 4. Main screen of the custom-built GUI developed to work with the 3D scanner prototype. It is shown the current first version (v. 1.0) of the GUI.

3. Preliminary results

After we have completed the development of a first version of our 3D scanner prototype including a stable version of the control software, we made some preliminary in-vivo measurements of different human skin surfaces. The results obtained in these initial testings demonstrate the general validity of the setup built and the implemented algorithms, but also highlighted some issues like the usefulness of implementing an additional algorithm to fill the existing holes in the 3D cloud of points or the need to improve the ergonomics of the prototype for its use in a clinical setting under a pilot study with patients.

Preliminary 3D measurements got with the current scanner prototype are presented in the next figures. Figure 5 shows the 3D reconstruction of a knuckle of the left hand of a male subject. The dense cloud of points obtained allows to see the relief features of the skin at a high resolution. The same happens with other skin areas scanned like for example a part of the thumb of the right hand of a male person shown in figures 6a. and 6b., or a small region within the palm of the hand of the same person which results are displayed in figures 6c. and 6d.

(a)
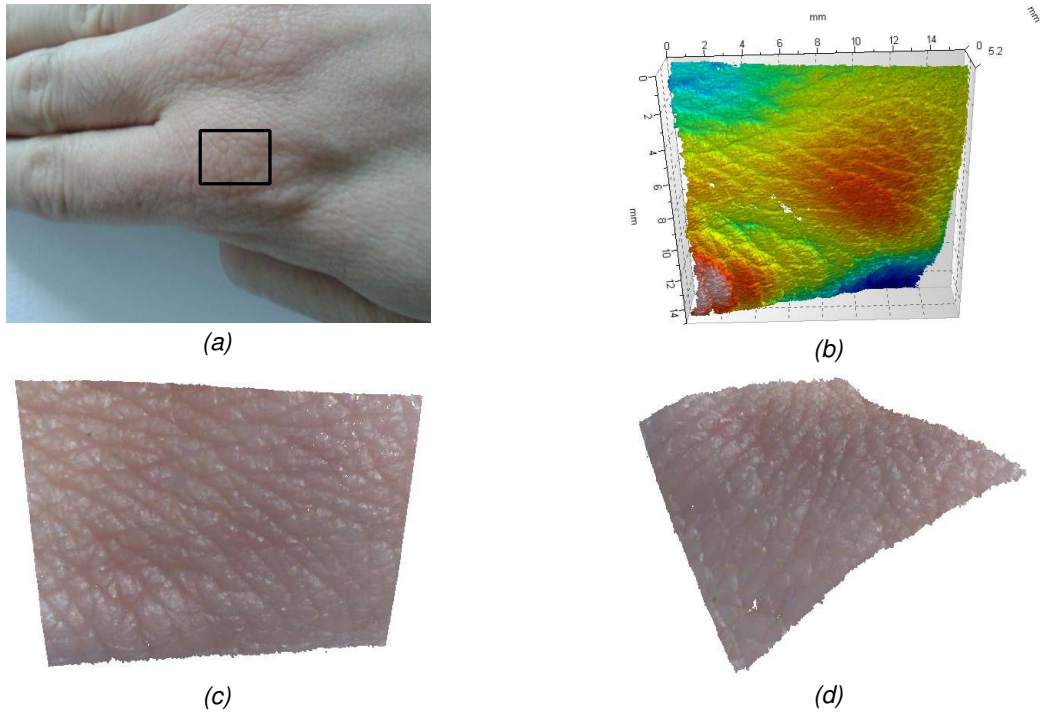

(b)

(c)

(d)

Fig. 5. (a) Scanned region of the knuckle of a human hand, (b) 3D reconstructed surface, and (c) and (d) different views of the 3D surface with the color texture superimposed.
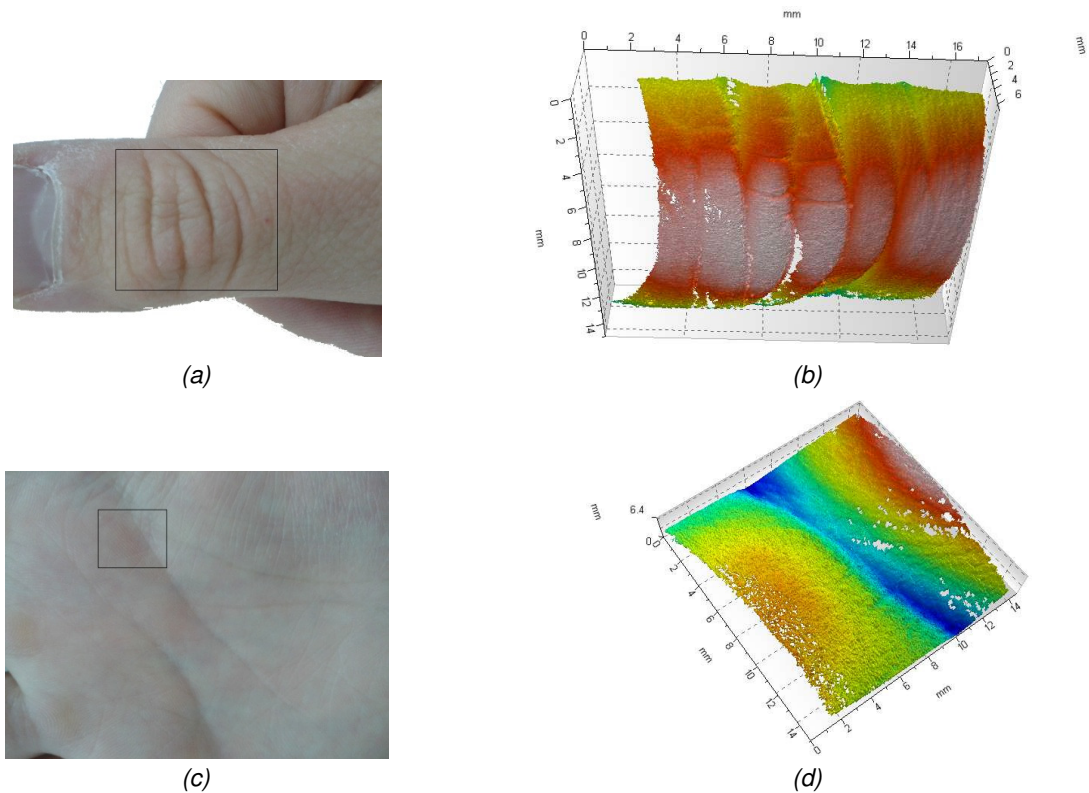

(a)

(b)

(c)

(d)

Fig. 6. (a) Scanned zone of the thumb of a human hand with (b) the reconstructed surface in 3D, and (c) the region in the palm of the same hand with (d) its 3D shape reconstruction.

4. Conclusions and future work

We have custom-built a handheld 3D scanner prototype based on the combination of stereovision and structured light projection techniques. The measurement procedure includes the synchronized projection and image acquisition of a set of phase-shifted fringe patterns over the skin, and the processing algorithms that calculate by triangulation the 3D data based on the corresponding phases between b/w cameras and the calibration parameters previously computed. This first version of the scanner has been developed using cost-effective components available at the market, which are basically a commercial picoprojector, a pair of monochrome industrial cameras, a color camera and standard optical fixed focal lenses. The system has been designed for measuring in-vivo the 3D topography of skin cancer lesions at a high resolution. It provides a 19 x 14 mm^2 full-field scanning of the skin surface, bringing out a dense 3D cloud of points with also the color information superimposed (X, Y, Z, R, G, B). A dedicated GUI has been also implemented to control the scanner by dermatologists and assistant nurses with a non-engineering knowledge in a clinical examination room with real patients.

A set of preliminary in-vivo 3D measurements of different human skin samples have been successfully carried out to demonstrate the capabilities of the prototype.

As far as the work is currently at initial stages of development, many different tasks are envisaged for the future work. In terms of the software, it will be developed an algorithm for filling the existing holes in a 3D cloud of points and also a set of algorithms that allows the extraction of relevant morphological parameters from the 3D cloud of points measured, in order to characterize the shape of the skin lesions. In regard to the hardware, we will improve the ergonomics of the 3D scanner for being able to test it in a clinical setting with real patients. The final goal is to carry out several pilot studies in different collaborating hospitals that provide a deeper insight about the potential benefits of the 3D characterization of skin cancer lesions for a better diagnosis and prognosis of the disease. Around 600 patients referred for moles in order to rule out a diagnosis of malignancy will be examined within the clinical pilot study. Doctors, nurses and managers of the hospitals will be implicated in the integration of the pilot in the clinical management of skin cancer patients.

Acknowledgments

References

[1] L. Chen, C. Huang, "Miniaturized 3D surface profilometer using digital fringe projection", in *Measurement Science and Technology,* 16 (5), 2005, pp.1061–1068, http://dx.doi.org/10.1088/0957-0233/16/5/003

[2] S. Logozzo et. al, "Recent advances in dental optics – Part I: 3D intraoral scanners for restorative dentistry", in *Optics and Lasers in Engineering,* Vol. 54, March 2014, pp. 203–221, http://dx.doi.org/10.1016/j.optlaseng.2013.07.017

[3] F. Berryman et. al, "A new system for measuring three-dimensional back shape in scoliosis", in *European Spine Journal*, 17(5), 2008, pp. 663-672, http://dx.doi.org/10.1007/s00586-007-0581-x

[4] W. Glinkowski et. al, "Method of pectus excavatum measurement based on structured light technique", in *Journal of Biomedical Optics,* 14(4), 2009, pp. 044041, http://dx.doi.org/10.1117/1.3210782

[5] C. L. Heike et. al, "3D digital stereophotogrammetry: a practical guide to facial image acquisition", in *Head & Face Medicine,* 6:18, 2010, http://dx.doi.org/10.1186/1746-160X-6-18

[6] L.N. Smith et. al, "Machine vision 3D skin texture analysis for detection of melanoma", in *Sensor Review*, Vol. 31, No. 2, 2011, pp. 111-119, http://dx.doi.org/10.1108/02602281111109961

[7] H. Skvara et. al, "Quantification of skin lesions with a 3D stereovision camera system: validation and clinical applications", in *Skin Research and Technology*, Vol. 19, 2013, pp. e182–e190, http://dx.doi.org/10.1111/j.1600-0846.2012.00625.x

[8] *Diagnoptics, CIP ICT PSP European research project,* http://diagnoptics.eu, 2013-2016.

[9] D. Malacara, *Optical shop testing*, 3rd edition, New Jersey: John Wiley & Sons Inc., 2007.

[10] D. C. Ghiglia, M. D. Pritt, *Two-dimensional phase unwrapping: theory, algorithms, and software*, Wiley-Interscience publication, 1998.

[11] R. Tsai, "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses", in *IEEE Journal of Robotics and Automation*, 3(4), 1987, pp. 323–344, http://dx.doi.org/10.1109/JRA.1987.1087109