Derma: monitoring the evolution of skin lesions with a 3D system

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Abstract

We present a new integrated tool, DERMA, which allows to measure and assess the time evolution of chronic wounds. A laser triangulation 3D scanner is used to acquire the wound geometry with high precision and to capture an RGB image aligned to the geometry. DERMA provides a single and uniform interface to: manage patient data, 3D scanning of the lesion region, and to perform different kinds of measurements and comparisons: geometric (on the 3D model) and colorimetric (on the image). All acquired data (3D geometries and images) as well as the measures calculated are stored in a database for monitoring the evolution of the skin lesion over time. The tool, developed in collaboration with dermatologists, is now under field evaluation in two dermatological clinics monitoring the evolution of wounds due to different types of skin diseases.

1 Introduction

The aim of DERMA project is to improve the capability of dermatologist to produce a numerically objective evaluation of the skin lesions status (see some examples in Figure 1) and to make possible monitoring their evolution through measurable attributes. The starting point of the project is the inefficiency of the traditional methods used for this purpose. The clinical evaluation of the extent of the damages due to a skin lesion and, moreover, the way a lesion evolves throughout time are often assessed according to the common sense and memory of the clinician. Evaluations are in general performed on the base of clinical experience and using very basic and low-tech equipments for collecting objective measurements. An interesting example is the common clinical approach to measure the *depth* of a skin lesion: a thin bar is introduced into the lesion until reaching the deepest point, selected according to clinician's evaluation; the bar is "marked" on the point corresponding to the potential skin surface height, and then measured by using a ruler. This procedure heavily relies on the skill of the clinician, and therefore is not easily reproducible.

Another important issue is how to *monitor* over time the evolution of a skin lesion. This is of basic importance both in clinical use and in pharmaceutical research. In the latter case, dermatologists assess the effectiveness of a pharmacological treatment by monitoring the evolution of selected type of lesions on a set of patients. The current clinical procedure is to take some notes, reporting an evaluation of wound status in natural language with some measures, usually paired with photos of the lesion.

An effective and accurate monitoring of skin lesions should be performed by measuring in an objective, precise and repeatable way the complete status and evolution of the skin lesion. The goal of DERMA project was to design a system which should provide features to monitor the qualitative and quantitative evolution of a skin lesion with an easy-to-use technology setup. The acquisition of the shape characteristics of a small skin section can be performed by using *three-dimensional scanners* [3, 1], in particular those systems based on active

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optical approaches. Some of these systems support also the integrated acquisition of the *color* of the scanned region, and color play a very important role in the analysis of the status of a skin lesion. The quality of current 3D scanning devices allows to get accurate geometric and chromatic characterizations of the skin lesion. This objective characterization allows to obtain precise measures, to archive all these data in a database and to support the easy monitoring through time of the skin damage.

Here we present the design and assessment of a system, called DERMA, whose goals are: to perform objective and precise 2D and 3D measures of the skin lesion; to adopt a non-contact approach, portable, fast and safe for the patient; to support the analysis of the status of the lesion through a joint characterization of the shape and of the colorimetric status of the wound; to enable easy archival of all data; finally, to support an easy comparison of the data or measures obtained at different times and to assess the evolution of the lesion through time with simple and reliable 2D and 3D graphics. These basic goals were defined by four European dermatological clinics (located in Italy, Great Britain, Denmark, Hungary) which participated to this project, working together with the technical partners in order to define the functional specifications of an "end-user-oriented" prototypal system. The demonstrative prototype is currently under test and validation thanks to the involvement of those end users (Figure 1 shows the system during its clinical testing).

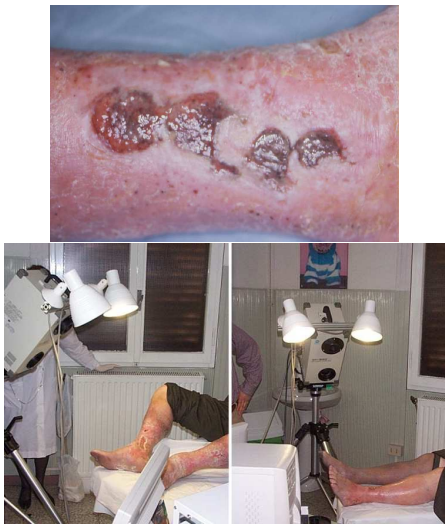

Figure 1: An example of chronical wounds (top) and the DERMA system under testing in clinical environment (bottom).

2 Previous research

Chronic ulcerative skin lesions interest around 1.5% of the European population and represent an important medical and social problem. The population affected by this pathology is generally geriatric and they often suffer from other concomitant illnesses. Chronic ulcers may set in for different reasons; they can be divided into the following main categories: vascular ulcers (venous, arterial, mixed), diabetic foot ulcers, pressure ulcers, and ulcers of various etiology. The above pathologies refer to chronic and invalidating conditions affecting the patients' quality of life and originating a depressive psychosocial attitude. New clinical treatments for these pathologies have permitted to improve lesion treatment and the quality of the assistance of medical and paramedical staff, while *lesion monitoring* methodologies have not improved together with this progress. The DERMA system has been specifically conceived on the basis of the needs of various qualified end-users and its functionalities will enable a substantial improvement of the crucial lesion monitoring phase.

The methodologies to obtain measurements currently used are very primitive: using transparent acetate sheets on the lesion to trace manually its perimeter, measuring the depth of the lesion by placing a bar inside it, or filling the lesion cavity with hypoallergenic material to produce a measurable cast. Most of the clinical diagnoses depends on the visual observation of the lesion. This is a rather inaccurate, non standardized method which heavily depends on the experience of the physician. Moreover, using this kind of techniques, it is very hard to monitor wound evolution over time.

Previous attempts of monitoring the evolution of lesions in a more objective manner include systems based on the acquisition of 2D images or video streams. System based on 2D color images have been proposed in [5, 11, 14, 15, 2]. In all these cases a characterization of the tissue status is reconstructed from the segmentation

of the RGB image, and some 2D measures are inferred from this segmentation (e.g. the wound area computed in the 2D image projection space). Calibration specimens are in general placed in proximity of the lesion, to allow color calibration and reconstruction of linear measures (i.e. a small ruler of known size). The only systems (as far as our knowledge) which propose the reconstruction of the 3D shape of the wounds are MAVIS [6] and MEDPHOS [9] systems. MAVIS adopted a prototypal 3D scanning system based on structured light [3] and reconstructed a 3D model of the tissue region; analysis and processing tools were provided by MAVIS (e.g. computation of volumes and surface areas) but the reported accuracy (about 5% of the region size, i.e. 0.5 cm on a region 10 cm. wide) was very low if compared to the accuracy possible with current technologies. On the other hand, MEDPHOS focuses mainly on the design of the 3D acquisition device: a special-purpose photogrammetric system (based on structured light and a trinocular vision system), where geometry is reconstructed by applying a photogrammetry approach – matching of corresponding points – on each set of three calibrated images.

Laser scanning systems have been introduced some years ago [3, 1] and have been adopted to produce very accurate 3D digital models in many different applications: entertainment industry, industrial quality control, rapid prototyping, cultural heritage, etc. The accuracy of the scanning systems improved in the last few years and prices also decreased, making these devices affordable for a wider community of potential users. The integration in a single system of capabilities to acquire the shape and the surface reflection characteristics (i.e. color) makes 3D scanning an invaluable resource in all those applications where we need to sample both surface attributes. The acquisition speed of some of these scanning devices is adequate to apply scanning to a human being, which could stay still for such a short time.

3 DERMA: system specification

The general objective of the DERMA project is to develop an efficient system for monitoring and assessing the status and evolution over time of skin lesions, which are typical of different pathologies. The overall goals of the DERMA project, according to the requests of the medical partners, are:

- to propose a standardization of the evaluation procedures in the dermatological environment, i.e. to define an *observation protocol* for skin lesions, which should determine the "significant parameters" which describe the evolution/involution of the pathology;
- the parameters considered in the observation protocol should be measurable in an *objective* manner by using the innovative technological tools. Objective skin lesion control and classification implies greater efficiency during treatment of the pathologies and, moreover, a large contribution to the work of researchers involved in the experimental sector which study the effectiveness of the new medical treatments;
- the technological tools should enable also the remote diagnosis and consult of a specialist or a specialized center that will define diagnosis and therapy.

From a purely technical point of view, DERMA has to support the following functionalities:

- 3D geometrical acquisition of skin lesions with very high accuracy;
- accurately calibrated [10] acquisition of the color attribute of the skin section considered and precise mapping onto the 3D geometry of the lesion;
- characterization of significant measures for the objective monitoring of various types of skin lesions. This includes both automatic measures (such as the surface extent of the lesion, its perimeter, the depth of the lesion, the volume delimited by the lesion surface and the hypothetical skin surface) and any point-to-point distance requested by the medical user;
- segmentation of the color attribute and integration of the segmented interpretation with the numeric measures taken on the 3D lesion geometry. Color characterization is important since areas with different colors correspond to different status of the tissue;
  item storing of all theacquired/computed data in a database, organized on a *per patient* and *per examination* base.
- comparative visualization of multiple acquisition (and associated data) to better evaluate wound status evolution.

Obviously, all the above functionalities have to be provided to the prospective clinical user with an easy-to-use GUI which should allow as much as possible an intuitive use of the system. The final system must obviously be extremely reliable, since diagnosis and medical treatment will depend on the system characterization of the lesion status. Finally, the system should be portable, fast and safe for the patient (non contact).

4 DERMA: system architecture

The functionalities of DERMA are implemented with a set of components, which are generally used in sequence. The user interface of all these components is divided in two sections: on the left we have all the widgets and buttons of the GUI (for data entry and visualization), while the larger section on the right is devoted to the output and to the graphical interaction with the 2D or 3D elements managed by each component. Interaction with the system is managed through distinct operative modes, each one related to a precise task/component: *Patient* – data archival; *Scan* – 3D acquisition; *Measure* – to take measures and to analyze the data; *Segment* – to segment the color data; *Compare* – to cross-compare data taken at different time.

4.1 Data archival and management

The initial window panel shown to the user is obviously devoted to the selection of the patient file. Since the main scope of the system is to monitor the evolution through time of the skin wounds, the organization and management of this information is a basic component of the system. All of the data acquired and processed by DERMA are stored using the **Oracle** Personal Edition DBMS. The first action is therefore to create a new data record for a patient or to select one of the previously examined patients. The patient record contains the classical data records: name, address, age and a free text field for annotations. Then, for each patient we have a list of *reports* each one containing the data acquired during the *i-th* examination and all the measures taken by the dermatologist together with his annotation and final referee report.

Obviously, the connection with the DBMS is completely transparent to the user; every request to the database is managed by DERMA components. All the information gathered by DERMA and automatically stored in the database; we describe those data in detail in the following subsections. The use of a DBMS enables the system to work even with the database residing on a separate server; moreover, database technology allows concurrent access to the patients data from multiple (remote) workstations.

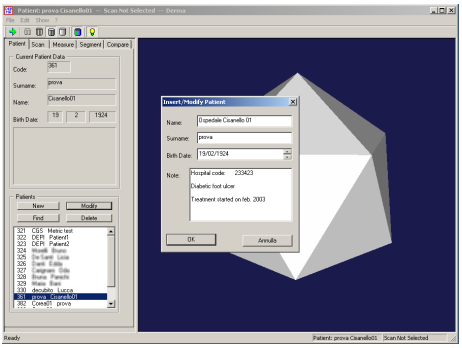

Figure 2: The image shows the *Patient* panel, provided by Derma to manage patient data creation, editing and displaying from/to the Oracle database (real patient names have been blurred for privacy protection).

4.2 3D model acquisition of skin wounds

A basic constrain of DERMA is the adoption of a non-contact technology for the acquisition of the shape of the lesion (due to obvious hygienic reasons). Therefore, we adopt an active optical approach, based on laser stripe sweeping and triangulation. Many different systems are available on the market; the main requisites guiding our choice were the speed of acquisition and the capability to acquire an RGB map aligned with the shape model. According to these requirements, we selected a Minolta VI910 scanner. The geometric accuracy and the sampling density (640*480 points sampled on an extent of approximately 20*15 cm.) provided by the Minolta scanner fulfill the requirements of the medical partners by obtaining a precision in the order of 0.2 millimeters. To ensure color fidelity in the acquisition process and avoid the color variations due to different lighting conditions we use a Colorchecker [10] to calibrate the contribution of

lighting environment. This is necessary because we assume the that the wound scans will not be done in a controlled environment, but in a normal hospital room. This calibration step has to be done just once before a scanning session.

The VI910's 640*480 color image is low resolution if compared with current digital cameras, but having an image which is exactly aligned with the 3D geometry simplifies considerably post-processing of the scanned data [13]. Moreover, since the extent of skin regions considered is just a few centimeters wide, the available resolution is usually sufficient to have multiple pixels per square millimeter. The only negative characteristics of the Minolta system are its weight (10 kg) and price: the VI910 cost (around 40K Euros) is competitive with the cost of other scanners or medical apparatus, but unfortunately still too high for many small clinics.

One important point for the success of a skin wounds monitoring system is the ease of use of the system. Therefore, we decided to get rid off the standard software tool provided by Minolta to drive the scanner. DERMA has been designed to be the only system the dermatologist has to manage, to improve the ease of use by providing a single tool able to manage the complete pipeline with a single conforming user interface. Therefore, a component of DERMA provides an interface to the Minolta scanner; this front end makes accessible to the user just the *necessary* parameters and commands of the Minolta scanner and it has been implemented using low level calls to the Minolta SDK.

To perform the scan, the user has just to frame the region of interest. A visual feedback is given to the user with a black/white monitor view refreshed every 1/2 seconds. Once the right focus area has been framed, user simply pushes the `Scan` button to start scanning. All scanner parameters are selected in an automatic manner; user can manually modify focus distance and laser power if needed (but the automatic selection feature provided works properly in most cases).

In the first experiments the scanner was managed with a standard tripod. The tripod allows easy panning but it is not so handy when we have to move the scanner nearer of further from the patient. To provide a smoother and faster manner to move the scanner we are designing a simple arm with counterweights.

3D acquisition is very fast (approximately two seconds). Some basic post-processing functions are applied to the data produced by the Minolta scanner, such as conversion of the range map to a triangulated mesh, deletion of low quality data, and filling of small holes. Every range map acquired is immediately shown in the output window on the right (Figure 3); this latter frame supports an interactive mesh browser. A standard trackball is provided to manipulate the mesh, together with standard rendering modes: shaded, wire frame, and texture mapped. User visual analysis is important to verify if the scanning was successful, i.e. to check that: the area of interest has been correctly framed; the patient did not move during the acquisition; the lighting was correct; etc. Once the dermatologist finds the current scanned result acceptable, he can

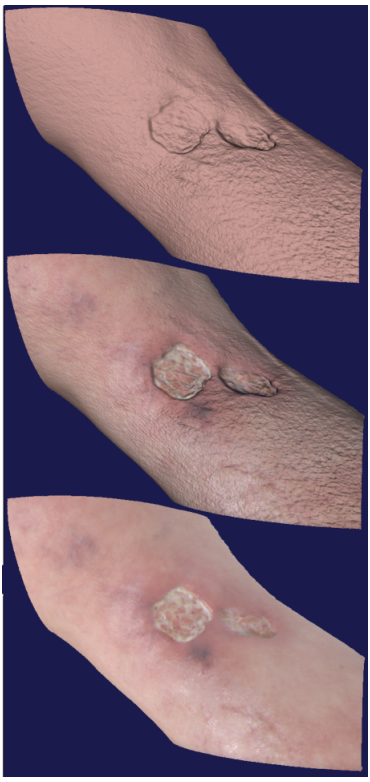

Figure 3: 3D rendering modes used by DERMA: geometry only, geometry with texture-mapped color data (and grazing light), or the textured geometry without lighting.

include this scan in the list of scans of the current patient (a new record in the list of scanning examinations of the current patient is created, containing the current 3D model).

4.3 Processing acquired data

Once a 3D model of the lesion has been produced, the computation of significant parameters has to be performed in an semi-automatic manner. Two related actions can be performed: firstly, the required shape-based measurements are computed; secondly, the associated color information is segmented to produce an image where colors would correspond to clinically-related classes of tissue status; and finally, the color segmentation is also integrated with the shape characterization.

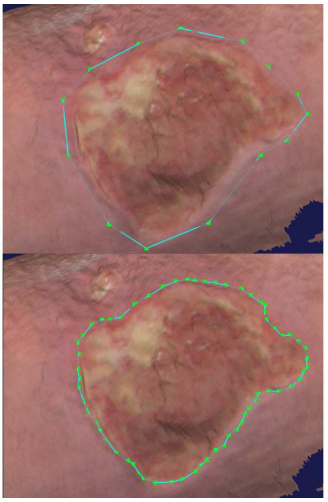

Figure 4: User-driven selection of the lesion border (approximate border shown on top) and the results of the further automatic refinement (bottom).

4.3.1 Shape characterization

The main clinical parameters deal with the measurement of: lengths (distance between critical points, depth of the lesion, perimeter of the whole lesion and of the different subregions defined by the color-based segmentation, etc.); surface extensions; and volumes (overall volume of the lesion). DERMA supports the following geometric measures.

Point-to-point distances can be obtained in a very easy way. Points pairs are selected onto the 3D model through a *point&click* approach; the segment connecting the points is displayed immediately with the associated length.

Perimeter of the skin lesion is firstly specified by the user with an interactive approach, and then refined by the system. Selection of the border of the lesion is performed in a semi-automatic manner: firstly, the user draws a closed polyline covering the border of the lesion. Then, the system improves the fit of this border with the 3D data by considering the shape and the color gradient of the selected areas: the initial polyline is refined, with the creation of new points whose coordinates are located in 3D space according to surface curvature and color gradient estimation (see Figure 4). The method used is based on the snakes approach [8, 4]. The user has complete control on the shape defined by this refinement phase, and can modify (interactive *drag&drop* of vertices) the location of any point which delimits the lesion boundary. Once the perimeter of the lesion has been selected, the computation of its length is straightforward.

Once we know the lesion perimeter, the corresponding *lesion-bed* (the surface delimited by the perimeter) is isolated and measured to obtain the *lesion surface*. After that, a surface patch corresponding to the hypothetical healthy skin passing through the same region is computed; we call it *lesion tap*. DERMA computes the lesion tap by interpolating a surface passing in the proximity of the wound border (a thin strip of healthy surface surrounding the lesion is enough to reconstruct in a plausible manner the shape of the original tissues), and produces a smooth triangle patch joined to the lesion border (see Figure 5). This patch is then used to give an estimate of the *healthy skin area* corresponding to the lesion region, to compute the *volume* of the skin wound (an important factor for some lesions which create deep cavities in the tissues) and finally to estimate the medium and maximum *distances* between the lesion *bed* and *tap* (i.e. the depth of the wound).

Perimeter, surface and volume measures are obviously performed on the 3D mesh, and therefore take into account the possible roughness or small protuberances existing on the wound. Any of these evaluated measures can be included in the *current scan* record; these data will enable comparisons with previous or future examinations.

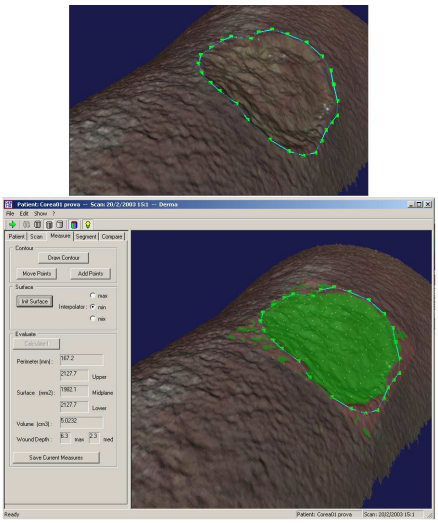

Figure 5: Given the perimeter of the lesion (top), an estimation of healthy skin surface is shown (bottom, healthy surface rendered as a semi-transparent green surface); wound measures are showed in the *Measure* leftmost panel frame.

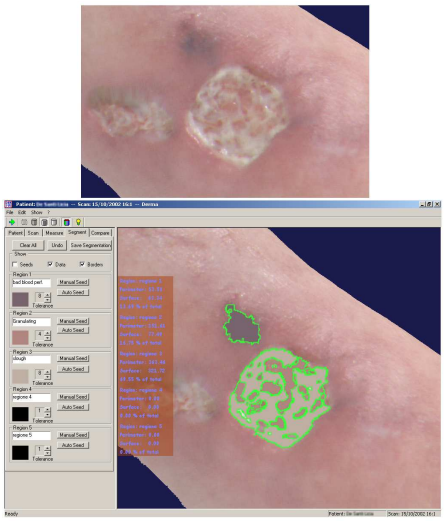

Figure 6: User-driven segmentation of the lesion color: three different tissue characterization have been selected and segmented (in this example: bad blood perfusion, granulated and slough tissue); the absolute and percentage areas are shown with the overprinted light blue text.

4.3.2 Chromatic characterization

A second analysis concerns the characterization of the chromatic data. The color of different tissues can be associated to a different status of the lesion. A segmentation step is therefore needed, to reduce the different color shades in the lesion region to a few, user-defined color clusters which are directly associated with a different clinical status of the tissue. Standard image segmentation techniques are therefore applied to the lesion image.

The color segmentation component of DERMA allows the user to interactively select a *color seed* (selecting a single color value on the image) and to start a *region growing* algorithm [12] which, according to a user-specified *similarity* parameter, builds a connected region (see Figure 6). This process can be completed by selecting new points and iteratively covering all the lesion region with a classified encoding. The region-growing algorithm works in a modified HSV color space (as stated in various articles [7, 2, 6], the RGB space cannot produce good results), using a similarity metric particulary suited to discriminate between the colors that are typically found inside wound.

In general, three main different classes are used by the clinicians: black necrotic eschar, yellow slough and red granulation tissue. Once we have segmented the lesion region in a few classes, the system computes some measures computed on the corresponding 3D mesh: perimeter, surface area and percentage of each class with respect to the wound extent. As usual, the segmented chromatic characterization and the computed data can be saved in the database and used in the comparison module.

4.4 Comparing different examinations

Given a selected patient, the dermatologist can retrieve different examinations results from the database and make a comparative analysis. The *comparing* component allows the user to select two/four examinations from the list of the current patient; data is retrieved from database and displayed in a joint comparison window. All the previously computed measures can be visualized on the associated 3D meshes. Mutual comparison of the

3D models is made easily with the possibility to *copy&paste* the view from one mesh viewer to the other one, in order to have a common view.

5 Assessment and Evaluation

The system evaluation is divided in two main phases:

1. assessment of the accuracy of the data acquired/computed, and of repeatability of results;
2. assessment of the positive effect introduced by the use of the system in the clinical environment.

Some test objects have been prepared to simulate wounds with known geometry. All the process, from acquisition to measurement has been performed from different people; in such way it was possible to evaluate both accuracy and repeatability. Results were positive, having a $< 2\%$ error on linear measures and $< 3\%$ on volumetric measures. Geometric measure performed from different people showed a $< 5\%$ difference. Color segmentation, more subject to human intervention, showed a $< 8\%$ variation. Similar tests, performed using real patients, showed more or less the same results.

For the second evaluation a clinical trial of the system is started in the two main partner clinics: University Department of Dermatology in Pisa and the Wound Healing Institute in Oxford, the planned duration of this on-field evaluation is one year to follow the evolution of the clinical conditions on a selected set of patients.

6 Results and Conclusions

We have presented the design and the features of DERMA, an integrated tool which allows to measure and assess the time evolution of chronic wounds. The system has been designed as a front end to a laser scanner, to allow the accurate and integrated acquisition of the shape/color features of the skin lesion. DERMA provides a single and uniform interface to: manage patient data, support 3D scanning of the lesion region, and to perform different kinds of measurements and comparisons: geometric on the 3D model and colorimetric on the image. All data acquired as well as the measures calculated are stored in a database for monitoring the evolution of the skin lesion over time. The tool is now under evaluation by dermatologists in two different clinics, which are focusing on the analysis and monitoring of lesions due to different types of skin diseases.

Acknowledgements We acknowledge the financial support of the Project EUTIST 1999-202226 “DERMA”.

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