On the use of Robotics in implant dentistry research.

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Abstract— The paper presented herein describes the development of an advanced robotized system applied to in vitro implant dentistry research. To the biomedical community this paper shows the possibilities of industrial robots to help the research. Robots are special suitable to the biomedical field specially when integrated with advanced sensors and technologies, which may facilitate both the programming tasks and the data acquisition. Robotics researchers will find in this paper one of the first applications of programming by demonstration with real users with a novel explicit robot programming technique making use of multi-camera vision combined with speech recognition. This programming method targets users who have minimal robot experience but aims at ‘teaching’ the robot to execute a specific task.

Keywords – programming-by-demonstration; service-oriented architectures; dentistry

I. INTRODUCTION

Research in implant dentistry is significantly constrained by the availability of reliable in vivo data come from clinical cases. The inherent differences between patients and the high variability of the implanting procedure turns collected data more imprecise and difficult to work with. To overcome this limitation we developed a versatile robotic system capable of executing several research procedures mimicking all the process of the implant technique and some of the living functions such as mastication. Robotics in medical research is not a novelty. Robots perform different tasks like automatic dispensing in pharmaceutical labs, mechanical tests of spinal joints [1] or stress/strain analysis in implant dentistry [2]. The choice of the robot as the principal element of the research system was driven by the needs of flexibility and repeatability. Assembled with a force/torque sensor and with appropriate software [3] this system presents high repeatability: less than 0.01 mm in position and less than 0.1 N in force. The global accuracy of the system enables highly reliable procedures that are being used, with minimum data, to validate different tests regarding misalignment caused by impression techniques, implants placing and mastication force distribution under numerous scenarios.

It should be noticed that the complexity associated with the research procedures promotes the interleaving between the researcher (dentist) and the robot: the robot executes operations when high degree of repeatability is required, like drilling, or highly repetitive tasks like photo-shooting p.e. On the other hand, the human (researcher) executes tasks non-critical for the reliability of the research procedures and also complex manipulation tasks like screwing the prostheses p.e..

Robot programming in this scenario is mainly a two step procedure: In the first step the position of one feature is determined by the researcher and afterwards the robot performs the operation with a set of different parameters. For mastication for example the researcher determines the position of the tool in the teeth and the robot applies the force in that position with predefined directions and forces. Our first experiments shown that the second step can easily be performed independently by the researcher with the help of appropriate software. Nonetheless, for the first step the presence of a robotics expert is mandatory. The alternative is the researcher program himself the robot, which represents a great challenge since it has non expertise in the field, is focused on other demanding tasks (research) and have to move his attention to do extensive reprogramming and adjustment.

Although offline programming tools have their important (growing) market, industrial robots are still very dependent on online teach pendant programming. This technology has suffered a great evolution over the past years [4] but the basic concept is still the same, and it is not well adapted to the scenario described above. Therefore, new paradigms for online robot programming are needed, with special focus on explicit programming techniques that can bring the worker or researcher closer to the robot. Recent developments
presented by a robot manufacturer have embedded high speed force control feedback into the robot controller [5], which provides good perspectives in terms of advanced sensor integration, crucial to improve the man/machine interaction. These systems have been around in research for a long time but their industrialization opens possibilities in mass products with advanced teaching techniques, namely Programming-by-demonstration [6][7].

The original contribution of the present work seeks two audiences, the research community in the biomedical area and the robotics researchers dealing with human-robot interaction. To the biomedical community this paper shows the possibilities of industrial robots to perform research specially when combined with advanced sensors and human robot interface technologies. Furthermore, a novel technique for the measurement of gaps between implants and the prosthesis is described. The robotics researchers will find in this paper one of the first applications of programming by demonstration with real non-expertise users, and the presentation of a novel explicit robot programming technique making use of multi-camera vision fused with speech recognition.

II. ROBOTICS IN IMPLANTOLOGY RESEARCH

A. Comparative study of impression materials

We developed a method for measuring the fitness of prosthesis and the corresponding dental implants. Since a robot arm is use for executing the dental impressions and part of the measuring procedure we gain high precision and reproducibility. This “in vitro” method for evaluating impression (methods and materials, see Fig. 1) that avoids the operator for executing both the impression and the measuring.

The proposed method is based on the use of a robot arm for performing the impression. For measuring the gap, between a realistic mandible made of a photoelastic polymer and the prosthesis obtain from the impression, we use the robot to move the high quality photo camera and take 6 zoom photos of each of the implants (Fig. 2).

Finally the results were analyzed with specifically developed software (Fig. 3).

B. Photoelastic analysis of implant arrangement.

The mastication force distribution inside the mandible is decisive in the durability of dental implants. The purpose of this study is to do a qualitative descriptive analysis of stress patterns around four different implants embedded in photoelastic mandible. The industrial robot equipped with a force torque sensor produces force controlled movements that mimic mastication forces that are propagated through the implants. Photo-elastic mandible acrylic resin models were die casted with four implants placed vertically and parallel between mentonian hole. Zirconia prosthesis was screwed to the implants and afterwards subjected to different loads (100N 150N and 200N) in 12 points with an axial force and 30° tilted (vestibular and lingual face).

Photoelastic analysis was accomplished using a reflection polariscope. The fringe patterns produced in the photoelastic resin for each implant and load were photographed with a digital camera. Fringe concentrations and the highest fringe order were recorded and described for the apical, central, and coronal regions of all the implants for each load scenario.
III. PROGRAMMING-BY-DEMONSTRATION

The interaction technologies used in the PbD system presented in this work are an infrared stereo vision system and a voice recognition system. The orchestration of these systems together with the robot is achieved using a service-oriented platform and a high level programming environment. The description of the methodology and implementation is presented in sections III.A, III.B, III.D.

A. Stereo Vision

The definition of trajectories is one of the crucial aspects in robot programming. Thus, accurate detection of position in a known frame is essential to accomplish this task. Although, there are several ways of performing such assignment artificial vision seems to be the easiest to be employed. However, when just one camera is used the problem of finding the correspondence between one point in the image and the point in the real world is undetermined since the dimension related to depth is lost. If other information is employed, such as other images taken from different angles, the 3D information can be recovered by proper triangulation.

In a broader sense, three-dimensional reconstruction depends on the initial information that is available. If the extrinsic and the intrinsic parameters of the camera are known the triangulation can be solved unambiguously. However, if only the intrinsic parameters are known, reconstruction is still possible but lacking one scaling factor. Even if intrinsic and extrinsic parameters are unknown reconstruction can be still performed based on the known correspondences but up to an unknown global projective transformation [8].

In the present work we were interested in recovering the complete 3D information, which was achieved by triangulation [8].

Figure 1 shows a schematic representation of the process: lines $\ell$ and $r$ passing through the points in the images ($p_\ell$ and $p_r$) and the corresponding center of projection ($C_\ell$ and $C_r$) would intersect at point $P$ in the absence of noise. However, the presence of noise inhibits in most cases that the intersection exists. Therefore, $P$ must be computed as the point that simultaneously minimizes the distance to both lines $\ell$ and $r$.

Point $P$ can be computed by:

\[ P = \frac{a \ p_r + T + b \ R^T \ p_\ell}{2} \]  

where $a$ and $b$ are calculated from:

\[ a \ p_r + c \ (p_\ell \times R^T \ p_\ell) = T + b \ R^T \ p_\ell . \]  

$R$ and $T$ are defined by:

\[ R = R_l \ R_r \ \ \ \ T = T_r - R^T \ T_l . \]  

$R_l$ and $R_r$ are the rotation matrix that represent the orientation of right and left cameras, respectively and $T_l$ and $T_r$ are the position of the centers of projection.

In order to determine the parameters of the cameras we used the method presented by [9] that was implemented in C#. In this method, a planar calibration object is placed in different orientations and their images are used to obtain the camera parameters. The parameters are initially estimated with a closed form solution and then refined using an optimization step. Radial lens distortions are also modeled.
B. Robot Jogging and robot services

The use of one single infrared LED provides significant advantages in terms of maneuverability in small spaces and in the required simplicity of use, but limits the jogging of the robot to translations. To overcome this issue we developed a simple strategy that uses the definition of a rotation vector making use of two points, according to the Fig. 6. The tool center point and the two points define a plane and an angle. The robot reorients the specified angle around the normal vector of the plane.

Fig. 6 Reorienting the robot with two points

It should be noticed that the translation movements of the robot can be made in either incremental or point-to-point mode (absolute positioning). The incremental movements permit to overcome some accuracy limitation of the stereo vision system.

The robot services were automatically generated from the robot program using software previously developed in the lab [10]. This software reads properly tagged robot programs and automatically generates network services.

C. Speech recognition system.

With the introduction of the language models, of which the n-gram [12] is by far the most used, speech recognition systems achieved remarkable efficiency levels.

Despite the need for further work on the recognition of conversational speech, speech recognition technologies regarding read speech are mature and ready to complement other means of human-machine interaction. These advances led to the development of several commercial products that are now reaching wider markets.

However, from a practical point of view, the most robust (speaker-independent) voice-enabled systems present in the market are still working in command mode, which means that the recognition is made against a predefined set of commands defined with special purpose grammars [13] [14].

In this work we use voice recognition grammars with a set of commands that allowed the researcher to complement the operation through the stereo vision system using voice commands to change the jogging mode and activate other functions (like photo shooting p.e.). The implementation of the network service for the voice recognition also uses automatic generation. Instead of robot programs this automatic generation uses the grammar from the voice recognition system (see [11] for details.).

D. Orchestration of services.

The concept behind the orchestration of services (or composition in a larger sense, according to [15]) is derived from the one introduced by distributed component-oriented programming, which, like in many other WS*-related technologies, was extended and standardized using XML specifications. From the evolution process, a standard has emerged as the most promising: Business Process Execution Language for Web Services (BPEL4WS) [16].

The integration of the voice recognition system and the infrared vision system was based on a service-oriented architecture using two well know platforms (UPnP [17] and DPWS [18]). In these platforms, network services are composed by events and actions and their integration of the programming-by-demonstration system is a partially unsolved problem. In the context of constrained purpose devices (like TV’s, p.e.) the use of such architectures is a success, but in the flexible scenario of a robotic workcell their major advantages is their integration with flexible integration languages/platforms. As described in [11], in spite of the existence of long-term consistent efforts on the specification of languages for the orchestration of services [19] [20], the event-driven nature of the robotic setup and the inadequacy of business level orchestration languages...
(like BPEL4WS) leads us to the use of state-chart based language and the respective environment previously developed on our lab (SidneyChart [21]) to orchestrate our services.

![SidneyChart interface with the statechart of the PbD system.](image)

The easy-of-use of the SidneyChart allowed the researcher (dentist) to perform himself some orchestration whenever a service changed, due to the change of the voice recognition grammar p.e..

IV. RESULTS

Concerning the stereo vision system the absolute error obtained with the present setup makes difficult the use of the robot to the intended application in absolute mode, but the incremental mode performance was satisfactory from the point of view of the researcher.

The performance of the voice recognition system is very high (>95%), due to the low number of commands used and the quality of the microphone.

V. CONCLUSION

The evaluation of the developed equipment in this work can be made from different perspectives. From the implantologist/researcher point of view the equipment provides the flexibility and repeatability required for the research procedures: 0.01mm in position, less than 0.1 N in force and when equipped with a high resolution camera is able to measure down to 1 micrometer of gap between implant and prosthesis. The global accuracy achieved with this system enables highly reliable procedures that are currently being used to validate different tests regarding implant misalignment caused by different impression techniques and mastication force distributions under numerous implants placing scenarios.

From the Human-robot interaction perspective this paper describes a programming-by-demonstration technique and its evaluation with a real user (the researcher). The results are very satisfactory. The researcher is now able to define new research tasks independently and even perform some orchestration of network services. This experiment shows that with proper tools in terms of human robot interface and advanced software tools for the integration of resources robots can perform a wide variety of tasks in new markets.

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REFERENCES


