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Force Feedback Control System Dedicated for Robin Heart Surgical Robot

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Abstract

3D contact force sensors were developed and integrated in a demonstration system for testing the feasibility of their application in minimal invasive surgery (MIS). Piezoresistive MEMS based vectorial force sensors were designed and fabricated by 3D silicon micromachining technology and packaged according to their proposed transducer and sensor applications. In this work we demonstrated the integrability and functional applicability of the 3D force sensors in MIS robotic systems to improve their flexibility and reliability by providing real-time force and tactile information during the operation.
The final goal is to integrate the new subsystems in the Robin Heart surgery robot of FRK. [1] Three different functions are targeted: 1. ***Micro-joystick actuator*** to be integrated in the hilt of the laparoscope to easily control robotic movement during operation. 2. ***Force sensor*** inside the laparoscopic jaw to provide feedback to the surgeon by measuring the grasping strength and 3. ***3D force/tactile sensor*** which facilitates palpation for tissue diagnostics during operation. In this paper we demonstrate a feasibility study regarding these proposed applications.

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Keywords: MEMS, 3D force sensor, piezoresistive, minimal invasive surgery, Robin Heart robot systems, real-time feedback

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1. Introduction

The lack of force feedback is one of the main barriers in the progress and widespread application of robotic surgery [2]. The main tasks of the surgical robot control (Fig. 1) are the mapping and analysis the movements of the surgeon operator (position/velocity and possibly other physical parameters), as well as facilitate arm movement by providing control signals to the actuators. Additionally desirable to reverse transfer the force/touch information to the person handling the tools. These signals can help the operator to make immediate correcting actions during the operation: cutting, separation, handle and move tissues, to care vascular clamping, to tie a knot, to recognize the type of tissue (pathology, calcification), to manipulate between different elements of internal organs without the risk of harming neighboring tissue, and also to sense collision of arms/or tools by automatic recognition.

Since the robot moves with 5 degrees of freedom (Fig. 1 right), activating the complex movement is available by the use of clutch switching control object. By choosing the appropriate mode the sensor provides the ability to control all the functions of the spherical robot: to lean forward or sideways or alternatively to penetrate or withdraw and to rotate of the tool axis. The feasibility of appropriate control system equipped with this novel sensor was investigated and compared with the classic remote control methods.

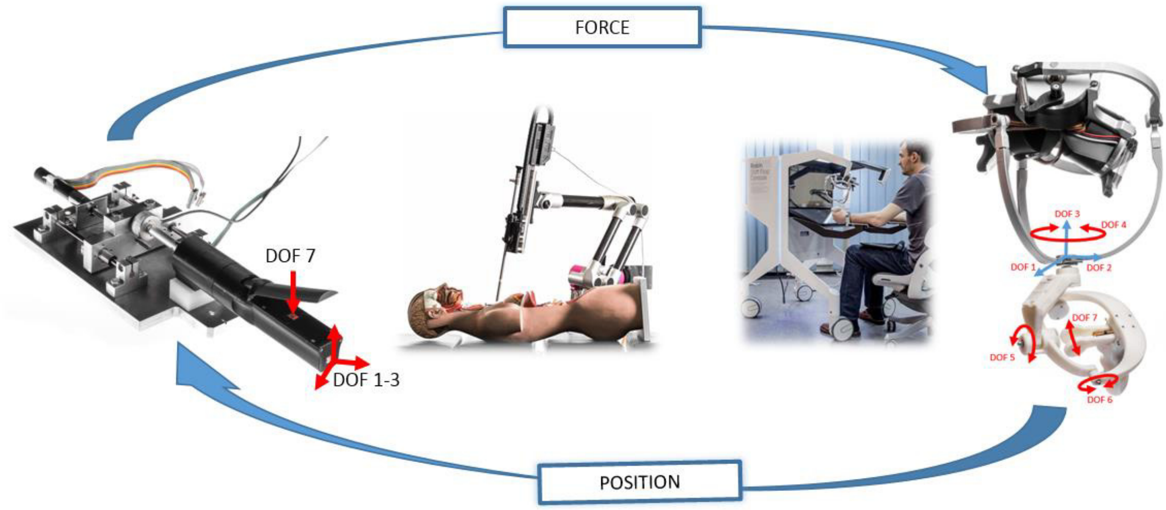

Fig. 1. Schematic representation of the master-slave systems with force-feedback and manipulation.

2. Force sensors in Robin Heart MIS robots

According to the preliminary results force sensors were designed and manufactured by 3D Silicon micromachining technology. The force sensor chip was mounted on a dedicated package and covered by a specially shaped flexible polydimethylsiloxane (PDMS) cap. The MEMS devices were integrated electronically and connected to the control system of the Robin Heart surgery robot. The functionality of the proposed MEMS sensors were simulated by FEM modelling and characterized experimentally.

2.1. Micro-joystick actuator

The subject aim of this work is to investigate the applicability of 3D MEMS based force micro-sensors made by 3D MEMS micromachining technology and use it as micro-joystick to control the position of robot Robin Heart PVA (Port Vision Able). The force sensors were assembled on flexible PCB and their application for controlling Robin Heart Vision camera was proved (Fig. 2).

Fig. 2. Prototype mini-joystick integrated in a laparoscope (top left) to control robotic arm movement.

2.2. Force and tactile sensing in the laparoscope tool

Preliminary tests of laparoscope integrated force sensors were also accomplished to provide additional on-line information for the surgeon during operation. The model tools were equipped with two 3D force sensors of MFA: one mounted on a tip of grasper for creation tactile signal, whereas the other directly inside the tool for measure the grasping forces (Fig. 3). The characteristics of each sensor were set to meet the special requirements of the given functions. Appropriate control systems and test beds have been developed at FRK.

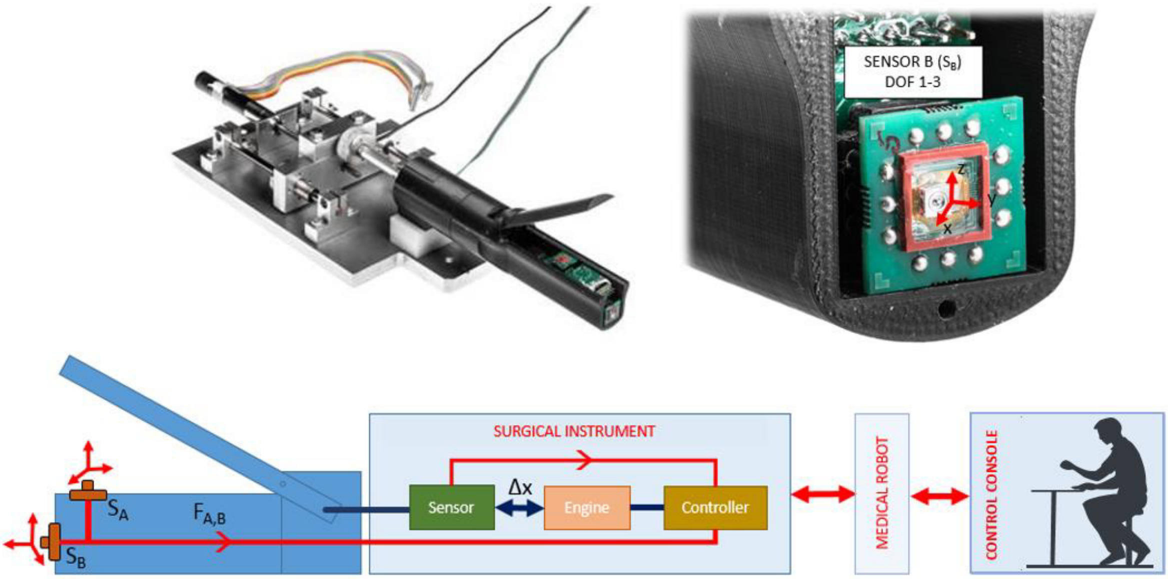

Fig. 3. Model of INCITE tools with tactile sensor on tip and grasping 3D force sensors inside.

Preliminary tests were accomplished to reveal the possible information the force/tactile sensors integrated in the laparoscope head can provide. Our work is also focused on the preliminary definition of the biomechanical effects present during surgical operations. Tactile measurements were also accomplished on artificial and real animal tissues to evaluate the applicability of the sensors for biomechanical screening during MIS surgery (Fig. 4).

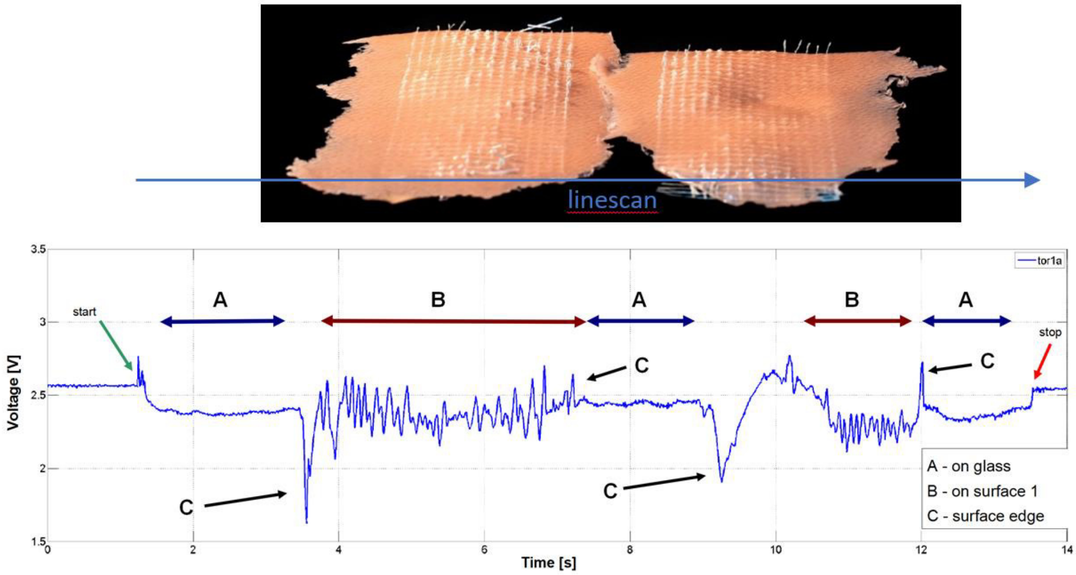

Fig. 4. Preliminary measurements for surface characterization by tip integrated tactile sensor.

3. Conclusions

A model of the robot controller using a prototype 3D sensor force, which has been successfully tested during the study of functional robot (robot control study performed during a surgical workshop with 200 people, students and doctors). Pre-studies of prototype sensors have demonstrated their usefulness in robot force feedback system to assess the state of tissue (tactile sensor for haptic information) and to assess the clamping force the grasper surgical system (acting force sensor for safety end precision working). Team work is continuing to reduce the size measuring system for typical surgical instruments and optimization (ergonomy) the surgeon control haptic devices (system) [3]. Developed devices will be used in preparation for the implementation of models of robot Robin Heart.

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