PART IV

Human Interface

12

The Design of a Functional STIFF-FLOP Robot Operator's Console

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Abstract

The chapter presents the development of a human–machine interface developed within the framework of the STIFF-FLOP project. The workstation concept of a surgeon is based on the assumption that the tool control method is consistent with the natural work of the surgeon. An integrated central unit (console) prototype was developed with several channels of bi-directional information flow between the robot and an operator. The STIFF-FLOP control console – Robin Heart – is equipped with two monitors, a haptic device with force feedback, and a foot-controlled button.

12.1 Introduction

The STIFF-FLOP robot consists of mechanical units, actuators, sensors, effectors, and a control unit. An important element of the proposed surgeon–machine interface is the introduction of the haptic feedback which provides the surgeon with sensations of touch and resistance to the tool tip, as they operate inside the body (Figure 12.1).

The Foundation of Cardiac Surgery Development (FCSD) team developed and implemented a control system of the console according to the requirements of medical systems and their safety (robust systems), as well as optimized the system of communication between the operator (surgeon) and the robot [1–3].

The specificity of the task lies in the limited space for the tool manipulation inside the human body. The user interface must not only meet the criteria of technical efficiency, but also accommodate the skills and experience of the

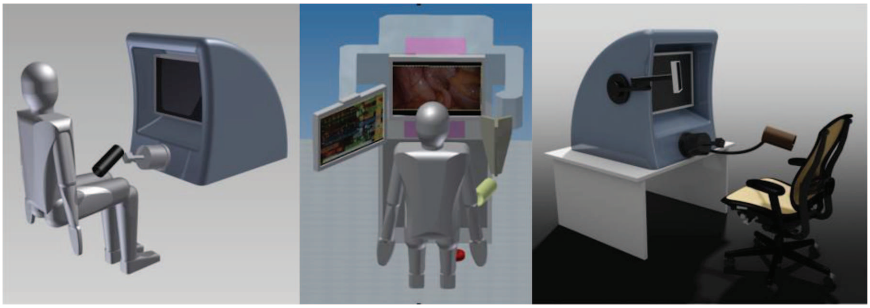

Figure 12.1 STIFF-FLOP console – design concept.

surgeon, typically acquired during the use of classical or laparoscopic tools. The moves made by the surgeon using the motion controller are mirrored by the robot. While during operations with a surgical tool (such as opening and closing scissors), as well as adding extra degrees of freedom and additional tasks (e.g., coagulation) of the end effector is performed by pressing a specific button or changing the position of the input controller.

The console model developed consists of a user interface, which allows the operator to control the position of the end effector. This is implemented by monitoring position and force feedback, obtained during the interaction between the robot and the environment. The action of the robot is visualized on a set of monitors in an ergonomic position for the operator. The operator can monitor and select the individual control parameters, such as scaling the motion, force, or the number of active sensors (Figure 12.1) [4–6].

12.2 Design of Improved Haptic Console

The control console is based on a user interface. The user controls the position of the end effector of the STIFF-FLOP robot arm. The haptic feedback information regarding the position and the operating forces is obtained during robot tool–environment interaction, using sleeves integrated with pneumatic or vibrating actuators to relay collisions between the robot's arm and the environment to the surgeon. The main console concept and the technical structure of the operator control unit are presented in Figure 12.2. Additionally, the operator can use a touchpad to set certain control parameters, such as scaling the motion or force, as well as adjusting the number of active sensors. The user interface RiH Delta *RobinHand F* haptic console was designed and developed using FCSD's experience from the previously conducted Robin Heart projects (Chapter 16): the interface allows the digital mapping of the

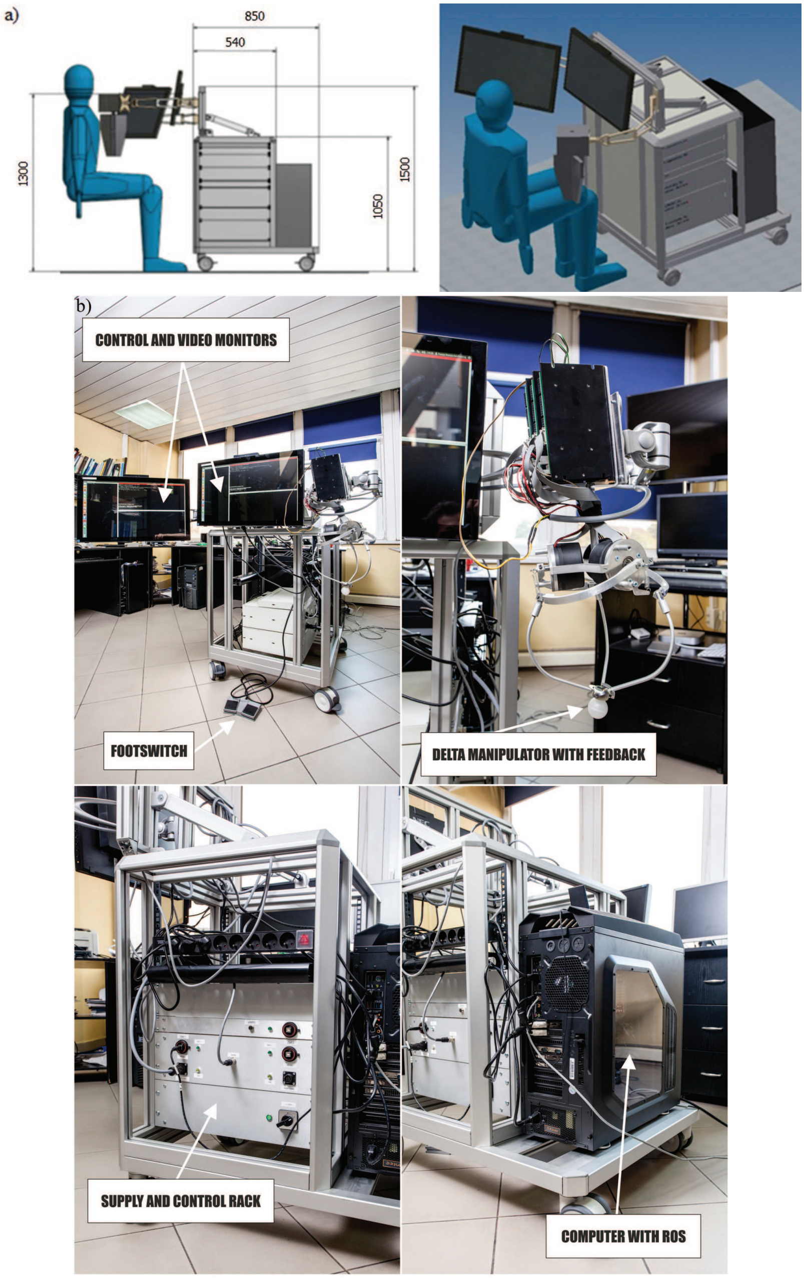

Figure 12.2 STIFF-FLOP console – (a) sketches of design concept and (b) modular prototype with components' description.

free movement of the surgeon's hands and lets the surgeon feel the force impact from the working tip (tools) of the robot operating in the environment of the patient by transferring it to his or her palm [7].

The STIFF-FLOP console includes:

1. Computer unit – with Linux and ROS (Robot Operating System);
2. Mechanical structure of the console body made from aluminum profiles' system;
3. Power supply and control rack system;
4. Two monitors;
5. Delta haptic device;
6. Haptic sleeve integrated with pneumatic/vibrating actuators (Chapter 14).

The STIFF-FLOP control console has a modular design based on a modular (rack) system. There are three different modules: power rack, vibro rack, and haptic rack (Figure 12.3).

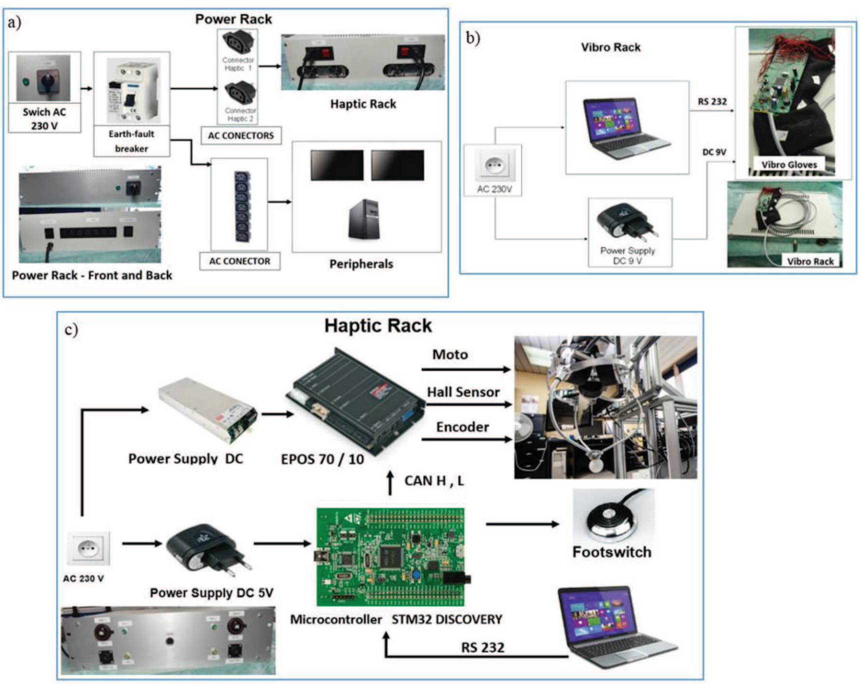

Figure 12.3 STIFF-FLOP console – Rack system: (a) power module diagram, (b) vibro module diagram, and (c) haptic module diagram.

12.2.1 Second Version of STIFF-FLOP Console

Further on, a second version of the console was developed. In order to reduce the dimensions of the console (Figure 12.4), the FCSD console has been modernized. In the first version of the console, desktop PCs are used to interface with the system using ROS. The amount of data processed was evaluated. To introduce a more cost-effective solution, a modular console using Raspberry Pi microcomputers was developed. The Robin STIFF-FLOP console has two of Raspberry Pi's microcomputers with ROS on board. Communication is established via TCP/IP protocol. One of the microcomputers communicates with the microcontrollers of the motion controller, while the second one controls the actuators of the robot. The whole system is designed to control the motion of the actuators, to analyze data from the sensors, and to control the force feedback.

The haptic control unit precisely determines the location and orientation of the tool tip in the three-dimensional space. The haptic control unit collects information about the positions of the arms of the integrated Delta interface, which is determined based on the voltage on the robot's motors. Motor controllers collect this information and convert it into position values in the Cartesian space. The reference point (origin) of the controller (0, 0, 0) was assumed for the minimum position on the Z-axis.

The microcontroller performs data acquisition of the force vector resultant from the interaction between the tissue and the STIFF-FLOP manipulator

Figure 12.4 STIFF-FLOP console made by the Foundation of Cardiac Surgery Development (FCSD) (first version).

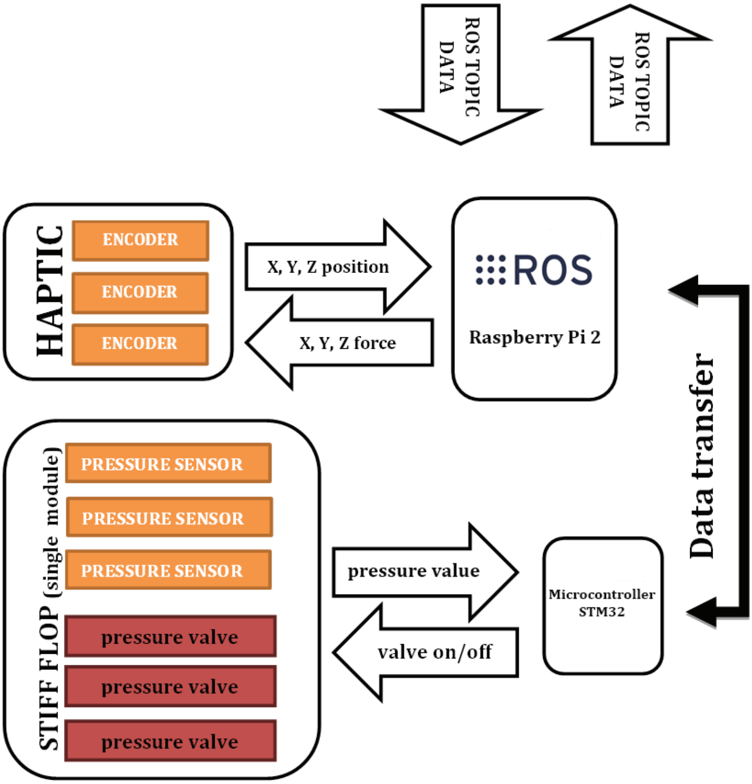

Figure 12.5 Control system (console and haptic) for the STIFF-FLOP arm, developed by the FCSD.

from the ROS environment. Further on, the force vector is transmitted to the haptic console. The console is ready to accommodate a vibration glove to enhance the haptic feedback on the surgeon's hand. The control structure of the STIFF-FLOP console for the STIFF-FLOP arm is shown in Figure 12.5.

12.3 Conclusion

The motion controller is a separate electromechanical system converting intuitive hand movements to continuous digital signal which enables controlling the robot's tools. The system may be equipped with modules which record, process, and transmit feedback data to the operator. The haptic feedback reflects, in a number of ways, the manner of interaction (force, optical, thermal, vibratory, etc.) between the tool/the entire arm and objects within the operating field. Signals carrying information about the operator's movements as well as feedback signals may be scaled and filtered, which is a great advantage of tele-manipulated devices. The control system of such devices must ensure the required accuracy and resolution of movement, rescaling the range of hand movements to the range of the robot's arms movement, and eliminate the effect of the operator's shaking hands.

It is assumed during console development that the tool tip actuation is performed intuitively and that the robot operator receives both visual and haptic feedback, which enables accurate control of the robot. The challenge of the STIFF-FLOP project was to allow the control of the tool tip mounted on an arm with a variable, controllable stiffness, and geometry. The operator of this type of robot, in addition to supervising the tool, should also have information about the position of the flexible, octopus-inspired arm. A set of sensors on the surface of the tool's arm (described in Part II of this book) transmits the information regarding contact or collision with other elements. For this reason, the FCSD team has developed a specially equipped console – an ergonomic surgeon's workstation. The console has been technically tested in the laboratory environment, as well as during experimental tele-operations – when the robot was remotely controlled from various distances. The work on the optimization of the console and the motion controllers, as well as the development of suitable software depending on the type of robot, tool, and surgical procedure are continued by the Zabrze team [6–11].

Acknowledgments

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