2014 5th IEEE RAS & EMBS International Conference on
Biomedical Robotics and Biomechatronics (BioRob)
August 12-15, 2014. São Paulo, Brazil

Integration of heterogeneous robotic systems in a surgical scenario

A. García-Martínez, L.D. Lledó, F.J. Badesa, N. García, *Member, IEEE,* and JM Sabater-Navarro, *Member, IEEE*

Abstract— **This paper defines what the authors named Modular Operating Room, as a heterogeneous system with different subsystems and devices that should interact between them in a surgical scenario. This is an evolution of the concept of Intelligent Operating Room, that has led us to large and expensive OR.**

The paper uses ROS to define a new package that manages the communications between different devices that can appear in a surgical scenario, in such a way that the real surgical scenario can be made with any combination of these devices. One simplified application consisting on the automatic insertion of an endoscopic camera on a trocar is shown as an example of integration.

I. Introduction

Several Intelligent Operating Rooms (i-OR) have been installed recently on leading hospitals. These i-OR's are complete surgery systems with advanced devices, and they have the goal of improving the patient safety and quality of the surgical procedure. The i-OR are advanced OR that can be used for several procedures, as Minimally Invasive Surgery, Robotic Minimally Invasive Surgery or open-surgery. Nevertheless, current i-OR’s are complex systems and the individual devices cannot be separated from the i-OR in order to be used separately [1], [2], [3].

Current i-OR are composed by several devices, as for example:

- Surgical Robots: Robotic systems that incorporates surgical tools that can be managed. Usually they work under a tele-operation control scheme. This scheme allows filtering the tremor of the surgeon’s hands and improving the precision of the movements.
- Surgical navigator: these are localization systems that control the external elements of the OR, as the manually operated surgical tools, the localization of the assistant hands. Usually they are 3D vision system or magnetic localization systems.
- Intraoperative imaging system: devices for on-line imaging. Examples of intraoperative imaging could be a laparoscope, intraoperative ultrasound (US) or fluoroscopy.
- Intelligent anesthesia systems: to control the state of the patient during the surgical operation.

Besides the cited systems, there are many other that are not principal on the surgical operation but they are also involved on it. Examples of these systems could be the system for image transmission or voice transmission on real-time, that allow the surgeon to get help from other doctor that are not physically on the OR. This is also used on new paradigm of teaching surgical techniques.

That way, due to the technological and commercial constraints, current i-OR's are complex technological solutions with several advanced devices connected between them. They are closed solutions, and the inner communications between devices are not accessible when trying to integrate a new device to work together with the existing ones. This make that current i-OR's must be acquired as a solely system, indivisible and with a high cost.

Nevertheless, the occasions in which the whole system is required for a unique operation aren't majority, since normally operations do not require of the use of all and each one of the built-in devices. In that case, it could happen that a device that is not being used in an intervention cannot be used with another patient because it is “blocked” by the i-OR, and then another system is required.

A. Modular operating room

As a solution to this problem the modular intelligent operating room can be defined. This Modular and Intelligent Operating Room (mi-OR) is a heterogeneous system of surgical devices that can be easily integrated and that they allow his use of individual form as much as forming different groupings. Thus, any device not used in an intervention can be used in other intervention, reducing the cost of procurement of equipment by the medical center and reducing the number of different systems that health workers must learn to control, for example allowing the control of different surgical robots with the same haptic control device.

Currently exist internationally recognized standards of medical communication, such as the DICOM (Digital Imaging and COmmunication in Medicine), which makes use of TCP/IP protocol and allows working with computerized systems for the digital archiving of medical images such as the PACS (Picture Archiving and Communication System).

*Research supported by National Grant DPI-2010-21126-C03-02.

All authors are at Neuroengineering Biomedical research group, nBio. (http://nbio.umh.es) Miguel Hernandez University, Avda. Universidad w/n, 03202 Elche, Spain. (corresponding author e-mail: alvaro.garciam@ umh.es).

.

II. MATERIALS AND METHODS

This section presents the components developed and the devices that were used at the simplified modular operating room used at our group, called nBio mi-OR:

A. *Hardware*

Control center. When trying to use more than a device on a system, we will need a control center, which is dedicated to manage the information and to take decisions about the whole performance of the different devices.

The Integration, Preprocessing, Analysis and Coordination Core (IPACC) has been defined as the center for interaction of all the devices, management of the communications and storage of all the send and receive data. Its function is to identify the devices involved in the operation, establishing communications among them and coordinate the received data, for example by analyzing the trajectories of the robots to avoid collisions.

Inside the IPACC we develop the ROSMedical Package, where the interface functions required are defined. This way, every Modular Operating Room has his own IPACC, being the only particular device that belongs exclusively to this OR.

Surgical navigation system. We use a cheap V120:Trio device from Optitrack, consisting on three infrared and pre-calibrated cameras. The cameras are able to find and follow several devices, as manual surgical tools, trocars or other devices. This way, the path-planning of the movable devices can be constrained with the information provided by the cameras. The data is obtained by the Tracking Tools software (provided by the manufacturer under Windows system), and this data is served to the IPACC using a VRPN communication scheme. We have also tried with an old Polaris system.

Haptic devices. Phantom Omni. We have integrated the Phantom Omni devices as a control device for some robotized tools of the Modular Operating Room. This way we can have a haptic feedback when teleoperating a robot. The spatial coordinates and the events of pushing a button on the Phantom device are sent to the IPACC using VRPN communications. The spatial transformations between the global framework and the phantom coordinates are managed at the IPACC.

Surgical robot. Imhotep. Imhotep is a 3UPS1S platform (figure 1) used as a surgical wrist. It is composed of three legs, in which each leg has three joints: a spherical joint that links the lower platform with the leg, a prismatic joint that is used by the actuator, and a universal joint that links the upper platform with the leg. As figure 1 shows, the 3UPS1S proposed here has the special feature that its rotation point P is located over the 1S joint, in the lower platform of the device, and that is coincident with the insertion point of the surgical procedure. This feature allows to fit the P point over the trocar, in such a way that the rotations of the MIS tool are always safe. [4]

Figure 1. Imhotep surgical wrist.

Imhotep device is actuated by 4 linear DC motors from Faulhaber. The developed control for this device sends the Cartesian and Joint coordinates to the IPACC using a UDP communications protocol. Spatial transformations between the global framework and the Imhotep coordinates are managed at the IPACC.

Outer Robotic arms. One (or more) robotic arms can be also integrated on the system. In this paper we have work with two UR5 robotic arm from Universal Robots. These arms can be used to support other devices, like the endoscope, the Imhotep device or any other they can manage. Figure 2 shows the setup of the platform.

Figure 2. UR5 robotic arm used on nBio Modular Operating room

UR5 arms are controlled using a specifically developed ROS node, which creates a TCP communication between the robotic arms and the IPACC.

Dynamic simulator. Consists of a simulator with interface functions able to recreate both patient inside and the tools that will be used during the intervention [6]. Its function will change depending on the phase of the intervention:

- During the preliminary phase, the simulator will recreate in a 3D environment the intervention allowing the surgery to plan choosing the right tools, looking for the best paths to the involved internal organs, etc.
- During operation it will function as an interface between the embedded devices in the system and the surgeon, allowing display at all times the parameters influencing the intervention.

Since is received all data from the remote devices, allows recording of intervention for review (for example for legal proceedings) o for use in teaching, and may even recreate with this data the operation in a 3D environment that allows a whole view.

B. Communications

Communications are mostly based on UDP, which allows delivery over the network without having previously established a connection. Nor has confirmation or flow control, so that packets may arrive in the wrong order; and it isn't known if they have arrived correctly, because there is no delivery or reception confirmation.

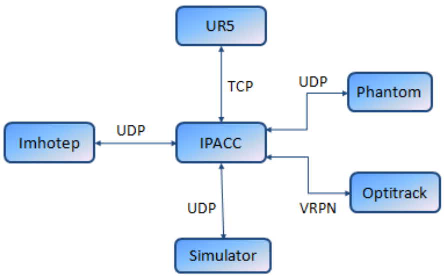

Figure 3. Communication scheme

It has the advantage of being a fluid communication without pauses. This communication channel is useful for exchanging continuous communication, such as the position coordinates of a device.

For those devices that requires a guaranteed delivery it's necessary a identification system and a completion signal for each command send by the IPACC. Thus, the control center could confirm the completion of a particular command or re-sent if it's necessary.

The UR5 robotic arm is controlled by a specifically developed ROS node that has been implemented with a communication protocol that allows the execution of different commands by the robot.

As figure 4 shows, communication begins with the submission by the computer of an identifier number that specify the type of command to be executed (rectilinear path, curvilinear path, position change of the TCP and so on). Once the robot knows the type of command to execute the appropriate subroutine will begin, sending a confirmation to the computer to start the transfer of the necessary parameters. This part of the communication may require new shipping acknowledgments by the robotic arm.

Once the parameters have been sent and the UR5 has executed the requested order, it sends a completion signal to the computer to repeat the process with the submission of new commands.

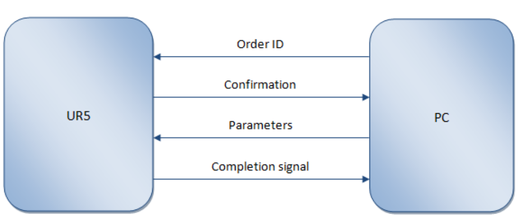

Figure 4. Communication protocol

Every device connected to the system will send an integration signal that will help the IPACC to continually confirm the connection. This signal may be a normal delivery of data between both devices (such as position coordinates) or a signal generated exclusively for this purpose.

If the integration signal is lost during the operation, the IPACC must immediately notify the absence of the device and coordinate the other elements in the event of it being impossible the reintegration.

C. ROSMedical Package

ROSMedical is a ROS package that contains all the executable and tools necessary for the proper function of the IPACC control center, which manage the nBio mi-OR. When executing the package it will create all nodes and communication channels required for each peripheral device that could be integrated into the system, recognizing the IPACC that will be used in the intervention as it receives its integration signal.

A node for dynamic simulator: *simd_node*.

A node for each Phantom integrated: *phantom_XX*.

A node for each element tracked by the camera: *optitrack_XX*.

A node for each outer robotic arm: *UR5_XX*.

A node for each Imhotep surgical robot integrated: *imhotep_XX*.

A central node MASTER (don't confuse it with the ROS node master) acting as a bridge between other nodes, which will not communicate or see each other.

III. Experimental Test with Our Modular Operating Room

To test the ideas discussed in this article we have implemented in the laboratory a simplified recreation of the nBio Modular Operating Room. The test consists capturing by the Optitrack camera of a trocar object where infrared markers have been attached. Then, the camera sends the coordinates to the IPACC and the IPACC provides the trajectories to the UR5 arm to introduce the laparoscope into the trocar.

The elements used for the test have been a V120 Camera: Trio Optitrack, a trocar provided with a series of IR marker spheres (figure 5) and a UR5 Universal Robots robotic arm with a laparoscopic camera attached to its end effector, all coordinated by the IPACC.

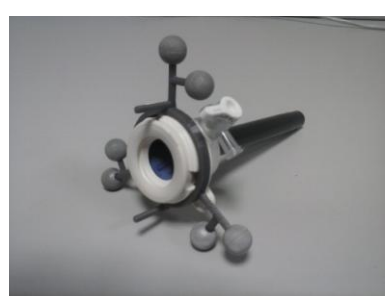

Figure 5. Trocar and IR marker spheres

For the integration of the devices we have programmed a simplified version of the ROSMedical package. It will take position coordinates and orientation of the trocar through VRPN protocol of the Optitrack. Orientation is provided as quaterion, so it will require a transformation to axis/angle orientation, as the UR5 arm works with them. The transformed coordinates are sent via TCP/IP sockets (figure 6).

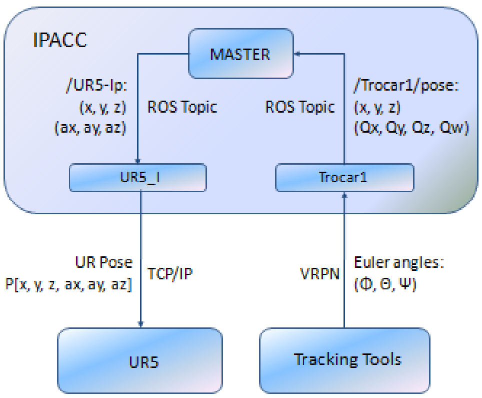

Figure 6. Experiment scheme

In the IPACC we have programmed the publication of two topics, one called /Trocar1/pose with the coordinates of the trocar in the camera frame and another called /UR5-Ip with the coordinates of the trocar in the robotic arm frame.

To carry out the transformation from one frame to another (figure 7) we use transformation matrices in order to allow matrix calculation on the code, and finally transform it to axis/angle coordinates.

$$A_{Pext}^{UR5-I} = A_{Aux}^{UR5-I} \cdot A_{Opt}^{Aux} \cdot A_{Trocar\,1}^{Opt} \cdot A_{Aux\,2}^{Trocar\,1} \cdot A_{Pext}^{Aux\,2} \quad (1)$$

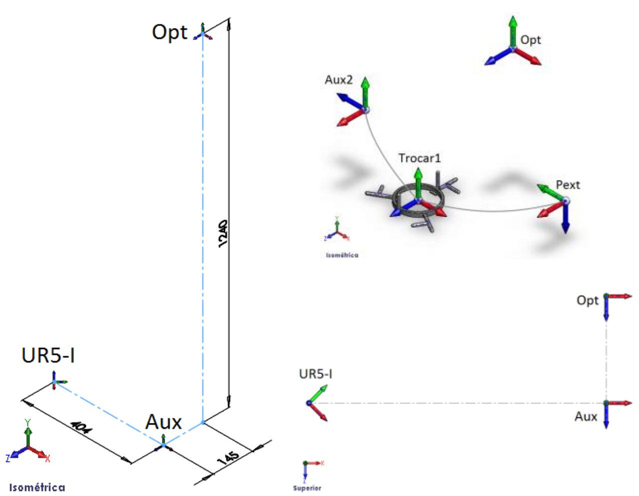

Figure 7. Involved frames

When starting, the connected devices are checked by IPACC. Then the IPACC transfer the trocar's transformed position and orientation coordinates to the robotic arm. The test finalized with the insertion of the laparoscopic camera into the training abdominal cavity.

IV. Conclusion

In this paper we propose a possible implementation of a modular i-OR, which could offer a reduction in purchasing costs of equipment required to perform certain operations.

We have used for programming the centralized controller the ROS framework due to its open software architecture and ease of programming. The developed package will automatically connect the external devices with the system and manage their tasks and communications. To check the proposed architecture we have carried out a small trial involving just two external devices, obtaining satisfactory results.

As future work we will seek an improvement in the communication protocols between the external devices and the IPACC. Finally we will continue developing a safety system which act in case of losing one of the devices, coordinating the remaining devices, so that they can complete the intervention as far as possible.

References

[1] Brecht Cardoen, Erik Demeulemeester, Jeroen Beliën, "Operating room planning and scheduling: A literature review", European Journal of Operational Research, Volume 201, Issue 3, Pages 921-932, ISSN 0377-2217, 2010.

[2] D Guzzoni, C Baur, A Cheyer, "Active, A Platform for Building Intelligent Operating Rooms", Surgetica, Computer-Aided Medical, 2007.

[3] T. Suzuki, K. Yhoshimitsu, HY. Muragaki, H. Iseki, "Intelligent Operating Theater: Technical Details for Information Broadcasting and Incident Detection System", Journal of Medical and Biological Engineering, 33(1): 69-78, 2011.

[4] J M. Sabater-Navarro, N. Garcia, C. Perez, E. Fernandez, R. Saltarén, M. Almonacid, "Kinematics Of A Robotic 3ups1s Spherical Wrist Designed For Laparoscopic Applications", International Journal of Medical Robotics and Computer Assisted Surgery. Print ISSN: 1478-5951. DOI: 10.1002/rcs.331 Volumen: 6 (3), pp: 291-300, 2010.

[5] https://github.com/ros-industrial/universal_robot.git

[6] J.M. Sabater-Navarro, M.L. Pinto, F.J. Badesa, R. Saltaren, C. Perez, JM. Azorin, J. Sofrony, "Force Reflecting Algorithm In Tumour Resection Simulation Procedures", International Journal of Computer Assisted Radiology and Surgery. Volumen: 4S1, pp:138-140, 23-27-, ISSN: 1861-6410, 2009.