A *portable* da Vinci simulator in virtual reality

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***Abstract*—Research activity in Minimally Invasive Robotic Surgery (MIRS) has gained a considerable momentum in the last years, due to the availability of reliable and clinically relevant research platforms like the da Vinci Research Kit (dVRK). However, despite the wide sharing of the dVRK in the research community, access to the platform remains limited because of high maintenance costs and difficulty in replacing components. In this work we complete a robotic simulator of the dVRK, previously developed by our group, with cheap haptic interfaces and an Oculus Rift to replicate and extend the functionalities of the Master console. The complete system represents an efficient, safe and low-cost tool, useful to design and validate new surgical instruments and control strategies, as well as provide an easy-to-access educational tool to students.**

I. INTRODUCTION

Augmented Reality (AR) and Virtual Reality (VR) are two modern technologies that have found wide application in healthcare and medical sectors, and are often involved in robot-assisted surgery. While AR is mainly involved to develop applications for user's perception enhancement [1] [2], major contributions of VR are related to medical teaching and practicing contexts, through the development of training simulators. Laparoscopic surgery is one of the sectors that benefited more of such technologies and of novel robot-assisted procedures, thanks also to the increasingly wide diffusion of the master-slave da Vinci robotic system and the da Vinci Research Kit (dVRK), that increased the use of Minimally Invasive Robotic Surgery (MIRS) in medical facilities, along with the necessity to develop specific simulation and training softwares [3]–[5]. However, such simulators are designed specifically for surgeons' training and do not provide a virtual reality simulator of the whole robot kinematics.

In this paper, we extend the functionalities of the open source da Vinci simulator proposed in [6]. In particular, we complete the simulator by providing a low-cost version of the Master surgeon console, to teleoperate the simulated robot and immerse the user in the virtual environment. For the purpose, a pair of Geomagic Touch[1] haptic devices and an Oculus Rift[2] virtual reality headset are employed. The system, of which we distribute the source code, is a valuable training environment for surgeons and students interested in earning experience with the robot, or in testing novel control techniques.

Fig. 1. The presented *portable* da Vinci simulated system

In the remainder of the paper, we describe the simulator and the devices adopted to reproduce the Master console, and show its effectiveness with a demonstrative training scene.

II. EXTENDING THE MASTER CONSOLE

The Master console sends commands to the Patient Side Manipulators (PSMs) through the pair of Master Tool Manipulators (MTMs), and shows the images acquired by the cameras mounted on the Endoscopic Camera Manipulator (ECM), through a binocular vision system. We use the pair of Geomagic Touch haptic interfaces to emulate the pair of MTMs, while the binocular vision is replicated through the use of the Oculus Rift. Aside from teleoperating the PSMs through the motion of the Geomagic stylus, this setup allows the user to freely move the head-mounted display (HMD) and to directly control the ECM through the heads movements, with a resulting fully immersive experience that also extends the capabilities of the real robotic system, as the camera view changes in a more intuitive way. As a result, the da Vinci Master console is emulated in a low-cost and easy-to-access fashion, thus realizing a *portable* da Vinci simulated system. The proposed simulator is built on top of the framework presented in [6], and exploits the *OpenHaptics* and *LibOVR* libraries to exchange messages and data with the Geomagic and Oculus devices, respectively. For system-based compatibility reasons, we replaced the communication mechanism based on Robot Operating System (ROS) - available only in Linux systems - with the remote V-REP APIs,to interface the virtual robotic system with an external application, as shown in Fig. 2a. This way, the application cyclically asks for the current joint configuration of the tele-operated PSMs end ECM, along with the images acquired by the vision sensor

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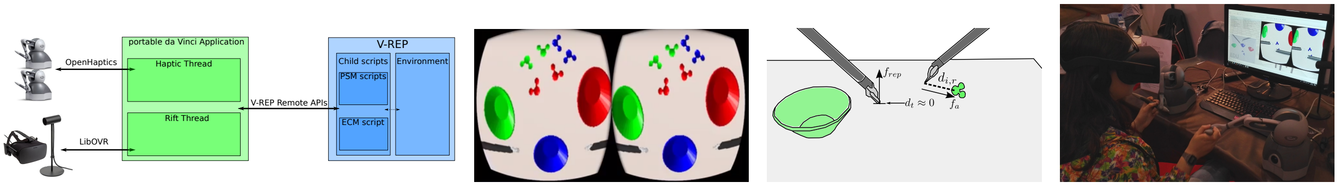
[1] https://www.3dsystems.com/haptics-devices/touch
[2] https://www.oculus.com/



(a) (b) (c) (d)

Fig. 2. (a) Module and device communication scheme of the portable da Vinci application. (b) Oculus view of the training scene. (c) Representation of the functionalities implemented in the training scenario. (d) Non-expert user testing the system at Maker Faire 2018 of Rome.

objects that simulate the endoscope. The resulting application communicates with each device on a separate thread, to keep the corresponding data acquisition rate unaffected.

1) Oculus Rift device connection: To properly tele-operate the endoscopic cameras of the ECM through the motion of the Oculus HMD, the corresponding velocities have to be kept consistent. For this purpose, pose and velocity measurements of the Oculus HMD are acquired through the Constellation positional tracking system, and used to build, through geometric considerations, the 6D velocity vector ${}^{\mathcal{C}}\boldsymbol{v}_{\mathcal{C}}$ of the endoscopic camera in its own frame $\mathcal{F}_{\mathcal{C}}$. The corresponding 6×4 Jacobian matrix $\boldsymbol{J}_{\mathcal{C}}$, reconstructed from the direct kinematics (see [6]), is used to map the camera motion to the ECM 4D joint velocity vector $\dot{\boldsymbol{q}}_E$. However, since the ECM is a 4-DoF RRPR manipulator, only 4 out of the 6 Cartesian velocity space dimensions can be assigned. Therefore, we alternatively control (i) the camera orientation, through the three revolute joints of the arm and (ii) the position along the longitudinal axis of the arm, through the prismatic joint of the arm.

2) Geomagic Touch device connection: Analogously, pose and velocity measurements of the Geomagic stylus, held by the user, are retrieved from the joint encoders of the Geomagic device, to build the 6D velocity vector ${}^{\mathcal{G}}\boldsymbol{v}_{\mathcal{G}}$ of the PSM gripper expressed in its own frame $\mathcal{F}_{\mathcal{G}}$, through twist matrix transformations. The device also provides force feedback along 3-DoF to reproduce physical contacts with virtual objects. We compute the corresponding Jacobian matrix $\boldsymbol{J}_{\mathcal{G}}$ in the gripper frame $\mathcal{F}_{\mathcal{G}}$, reconstructed from the direct kinematics, to map the motion of the gripper to the corresponding PSM joint velocity vector $\dot{\boldsymbol{q}}_P$, through matrix inversion. In this case, the 7-DoFs of the PSM (with the last one demanded to command the opening and closure of the gripper) allow to fully command the 6D desired Cartesian velocity. To cope with the geometrical heterogeneity between master and slave workspaces (known as *kinematic dissimilarity*), we use one of the stylus buttons to implement a *clutch*-based mechanism, to enable/disable the tele-operation of the slave with the master device upon explicit command of the user. This allows to relocate the stylus of the Geomagic in a more favorable configuration when the workspace limits of the device are reached.

III. SIMULATION

To show the effectiveness of the simulator, we developed a *pick-and-place* simulated training scenario, that consider a set of small rigid objects to be grasped and placed in three different cups on a table, while observing the scene from the endoscopic camera (Fig. 2b). To increase the user's sensory experience, we evaluate the distance $d_{i,s}$ $(s = \{l, r\})$ for each i-th object and render an attractive force f_a directed towards the closest one, so that it can be grasped and released by pressing the second button of the stylus. Furthermore, we also implemented a repulsive force f_{rep} on the planar surface of the table, to give the user the tactile experience of a contact of the gripper with a highly rigid object (Fig. 2c). This simulator has been also presented to the Maker Faire 2018 of Rome, and has been tested by several non-expert users (Fig. 2d). A comprehensive video, showing users performing the simulation described above, along with the source code of the simulator, can be found at the following link: http://www.diag.uniroma1.it/~labrob/research/portableDaVinci.html.

IV. CONCLUSIONS AND FUTURE WORKS

In this paper, we presented a full da Vinci simulator for the V-REP environment. Starting from a previously developed da Vinci simulator, we reproduced a low-cost and easy-to-access version of the Master console, using a pair of Geomagic devices and an Oculus Rift. We validated our simulator in a virtual training scenario, where both the force feedback and virtual reality functionalities have been shown. In future works, we will assess the effectiveness through a formal comparison with the real system, and we will improve the force feedback mechanism.

REFERENCES

[1] H. Delingette, X. Pennec, L. Soler, J. Marescaux, and N. Ayache, "Computational models for image-guided robot-assisted and simulated medical interventions," *Proceedings of the IEEE*, vol. 94, no. 9, pp. 1678–1688, Sept 2006.

[2] N. Cacciotti, A. Cifonelli, C. Gaz, V. Paduano, A. V. Russo, and M. Vendittelli, "Enhancing force feedback in teleoperated needle insertion through on-line identification of the needle-tissue interaction parameters," in *2018 7th IEEE International Conference on Biomedical Robotics and Biomechatronics (Biorob)*, Aug 2018, pp. 79–85.

[3] A. Baheti, S. Seshadri, A. Kumar, G. Srimathveeravalli, T. Kesavadas, and K. Guru, "Ross: Virtual reality robotic surgical simulator for the da vinci surgical system," in *Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, 2008, pp. 479–480.

[4] "Mimic Simulation dV-Trainer." [Online]. Available: http://www.mimicsimulation.com/products/dv-trainer/

[5] "da Vinci Skills Simulator." [Online]. Available: https://www.intuitivesurgical.com/products/skills_simulator/

[6] G. A. Fontanelli, M. Selvaggio, M. Ferro, F. Ficuciello, M. Vendittelli, and B. Siciliano, "A V-REP Simulator for the da Vinci Research Kit Robotic Platform," in *2018 7th IEEE International Conference on Biomedical Robotics and Biomechatronics (Biorob)*, Aug 2018, pp. 1056–1061.