Technical and Functional Validation of a Teleoperated Multirobots Platform for Minimally Invasive Surgery

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Abstract—**Nowadays Robotic assisted Minimally Invasive Surgeries (R-MIS) are the elective procedures for treating highly accurate and scarcely invasive pathologies, thanks to their ability to empower surgeons dexterity and skills. In the international research panorama of new prototypes for surgical tele-operated systems, a new master-slave robotic platform has been developed within the European funded project Smart Autonomous Robotic Assistant Surgeon (SARAS). The SARAS Multi-Robots Surgery (MRS) system is conceived to be tele-operated by an assistant surgeon during R-MIS. In this work, we will present the SARAS MRS platform validation protocol, framed in order to assess: *(i)* its technical performances in purely dexterity exercises, *i.e.* deriving from the motion-related parameters of the end effectors, to be compared with those of a reference da Vinci® system, and *(ii)* its functional performances, *i.e.* the level of accomplishment of surgical related tasks. The results obtained show a prototype able to put the users in the condition of accomplishing the tasks requested (both dexterity- and surgical-related), even with reasonably lower performances respect to the industrial standard. The main aspects on which further improvements are needed result to be the stability of the end effectors, the depth perception and the vision systems, to be enriched with dedicated virtual fixtures.**

Index Terms—**validation protocol, tele-operated surgical robotic system, robotic end effector task metrics, functional evaluation, surgical-related tasks**

I. INTRODUCTION

The advent of Minimally Invasive Surgery (MIS), both in its declinations as Laparoscopy- and Robotic-assisted procedures (L-MIS and R-MIS), has revolutionised the treatment of different pathologies, especially in the abdominal area [1]. Since the commercialisation of the first tele-operated surgical robot, the da Vinci® system (Intuitive Surgical Inc., Sunnyvale, CA) in 1999, and thanks to the ever increasing technological advancements of its successive releases, nowadays R-MIS has established as a gold standard for scarcely invasive surgeries like Radical Prostatectomy [2]. In fact, modern surgical systems offer to surgeons: *(i)* improved vision, through a three-dimensional visualization that provides depth perception [3], *(ii)* increased dexterity, thanks to the wrist-like articulations of the instruments mounted on the robotic arms [4], [5], and *(iii)* a better control of the surgical instruments, with tremor abolition and motion scaling, compared with standard L-MIS [1].

In recent years, researches in surgical robotics produced different prototypes of master-slave surgical robotic platforms for various purposes, like the Micro Hand S (Tianjin University, China) for R-MIS abdominal surgery [6] or the M7 robot (Stanford Research Institute, US) for ultra-sound guided tumor biopsies [7]. It is within this context that the present work lays its ground: the EU funded *Smart Autonomous Robotic Assistant Surgeon* project (SARAS, saras-project.eu) aims at developing a new generation of autonomous surgical assistant robots for R-MIS, thus allowing a single surgeon to perform the procedure. To reach this challenging purpose, a preliminary tele-operated version of the future autonomous robotic system has been implemented: the so called *SARAS Multi-Robots Surgery* (MRS) platform [8]. It is conceived as a master-slave robotic system, to be used by an assistant surgeon (who usually operates with standard laparoscopic tools), while s/he is supporting the execution of a R-MIS procedure.

In the present contribution we present the validation protocol drawn, and the results obtained, in order to test the performances of the SARAS MRS platform, and to preliminary assess the related suitability in carrying out its intended purpose. Taking into account that, for the operating surgeon, robotic surgery skills are composed by a mixture of human-computer interaction skills (like a good spatial and depth perception in 3D vision with a mediated hand-eye coordination)

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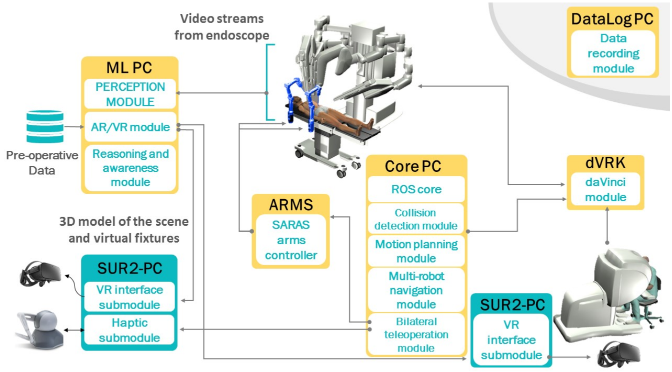

Fig. 1. Multi-Robots Surgery (MRS) platform architecture.

and the traditional surgical technique [9] [10], complementary aspects have been taken into account while framing the validation protocol. First, in order to evaluate the dexterity-related performances of the SARAS MRS prototype while executing simple manipulation exercises, specific metrics, from the robotic systems motion-data collection, have been considered. These are meant to be compared with those emerging from the execution of the same exercises with a reference commercial robotic platform for surgery (*i.e.* the da Vinci® IS 1200 controlled by using the da Vinci Research Kit, dVRK [11]). This part of the protocol is going to be later referred as the *technical validation*. Then, a more qualitative investigation is carried out, in order to assess if the operator is capable of correctly fulfilling simple surgical-related exercises, which are meant to train motion and cooperation skills preliminary to the real surgical practice. For this reason, this second part is addressed as *functional validation* and it is concluded by the execution of specific steps of a simplified Robotic Assisted Radical Prostatectomy (RARP), by real surgeons teleoperating the da Vinci® and SARAS platforms, on synthetic abdominal phantom models [12]. The phantom models have been designed and produced by the Austrian Center forMedical Innovation and Technology (ACMIT)[1] [8].

The rest of this paper is organized as follows. In Section II, the Multi-Robots Surgery platform is described; in Section III the validation protocol for the assessment of the MRS platform is presented. Section IV and Section V, respectively, detail the results of the technical and functional evaluations and discuss them. Conclusions are drawn in Section VI, together with a discussion on the future perspectives of this study.

II. SARAS MULTI-ROBOTS SURGERY PLATFORM

The SARAS Multi-Robots Surgery (MRS) platform is an example of multi-master/multi-slave (MMMS) bilateral teleoperation system, where two users cooperate on a shared environment by means of a telerobotics setup. The overall system architecture is reported in Figure 1. In this scenario the main surgeon controls the da Vinci® tools from the da Vinci® console, whereas the assistant surgeon teleoperates standard laparoscopic tools mounted on the SARAS robotic arms. They are controlled from a remote station equipped with virtual reality and haptic devices. The assistant surgeon will perform the same actions as in standard robotic surgery, but here by teleoperating the tools instead of moving them manually.

A. Assistant master console

The assistant master console (see Fig. 2, left) consists of:

- Two G-Coder Simball (R) joysticks[2], used by the assistant surgeon to teleoperate the assistive robotic arms,
- Two 3D Systems Touch (R) haptic devices[3], to apply force feedback on the users hands, and
- An Oculus Rift device[4] used to stream the da Vinci® endoscope images with augmented information.

Simball is commonly used to train surgeons on laparoscopic operations, due to its ability to emulate with realism the feeling of a real laparoscopic instrument (in particular the mechanical constraint of the trocars through which the instruments are inserted into the peritoneum of the patient). The Simball device is bound to the end effector of Touch haptic device, allowing to propagate the force feedback generated by the haptic device to the surgeons hands. With this configuration the assistant surgeon can feel virtual objects with a true-to-life touch sensation.

We use virtual reality to improve the visual feedback provided to the operator. By using pre-operative and intra-operative data we produce virtual fixtures (*e.g.* virtual walls impassable for the tools or optimal paths the surgeon is guided to follow during delicate phases of the procedure) to help the surgeon safely navigating the human body [13] or to enhance his/her 3D perception [14]. We use the Oculus Rift device to provide the necessary visual feedback to the assistant surgeon while the main surgeon access the same information on the da Vinci® console monitors.

B. Robotic arms

Each SARAS robotic arm (see Fig. 2, right) consists of three different modules:

1) one passive *Positioning Arm* with 7 degrees of freedom (DOFs) for rough positioning of the instrument,
2) one *Fine Positioning Robot* with 3 actuated DOFs to position the instrument,
3) one *SARAS Adapter* with 1 DOF as slot for different surgical tools.

The *Positioning Arm* is a passive mechatronic device – *i.e.* the arm can only be moved manually– for holding and positioning surgical instruments via passive adapters or active robot end effectors. It is fixed to the operating table by an integrated clamp and can be moved and locked in different positions to enable the accessibility of the operating field. The *Fine Positioning Robot* is an active mechatronic device for holding and guiding the instruments during the surgery. It is mounted on the final link of the Positioning Arm and allows for spatially limited but extremely precise movements of the

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[1] http://www.acmit.at

[2] http://g-coder.com/simball-duo

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

[4] https://www.oculus.com/rift

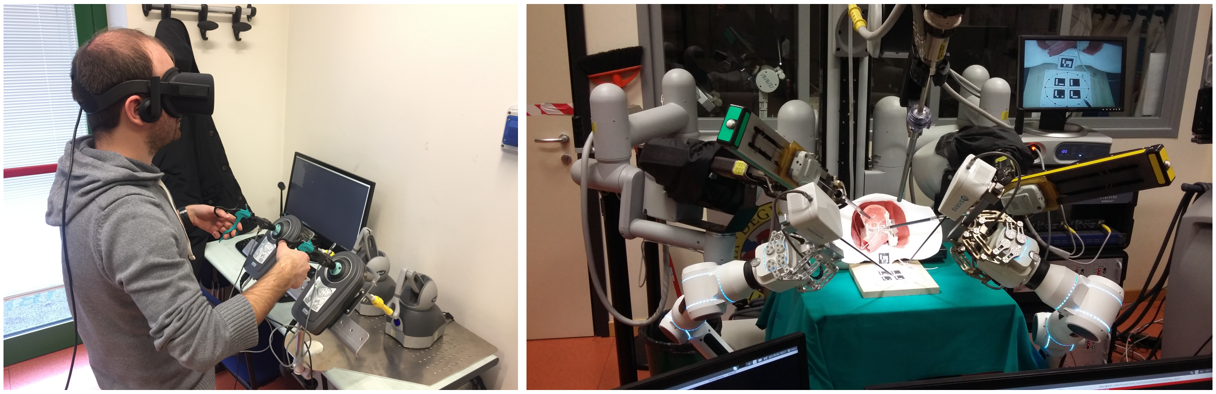

Fig. 2. The SARAS Multirobots Surgery platform implementation: master console (left) and robotic arms (right).

instrument. The motion is guaranteed by two identical actuated kinematics chains followed by a linear actuator for the vertical motion. A specific API of the system allows to fix the remote center of motion along the main axis of the laparoscopic tool where the corresponding trocar is located. The *SARAS Adapter* is an active mechatronic device for holding and guiding the endoscopic instrument. It is attached at the end of the Fine Positioning Robot and is only responsible for the last degrees of freedom of the surgical tool –*i.e.* opening and closing the tool (scissors, forceps, clip appliers, etc.) and rotating around the main axis of the tool.

The SARAS arms have been designed and produced by Medineering GmbH[5], a partner of the SARAS consortium.

C. Bilateral Teleoperation Architecture

Safe and stable interaction between master console and robotic arms is achieved by means of a passivity based two-layer architecture introduced in [15] and applied to surgical robotics in [16], [17]. In particular, the framework is composed of two layers placed in a hierarchical structure. Each layer is designed for a specific purpose: the upper layer to obtain transparency (*i.e.* the user gets the experience that s/he is directly manipulating the environment), the lower layer to maintain passivity (*i.e.* the energy which can be extracted from the system is bounded from below by the injected and initial stored energy) and, therefore, guarantee a stable behavior of the teleoperated system.

III. VALIDATION PROTOCOL

SARAS MRS is a prototype tele-operated platform meant to be able to cooperate with another external robotic system during R-MIS. Therefore, the validation, and corresponding evaluation, of its performances embraces different aspects: *(i)* its capability to reproduce the intended movements of the operator, *(ii)* its ability to perform single and cooperative surgical-related tasks, and *(iii)* its effectiveness in performing the needed passages during a simulated surgical procedure. On this basis, the validation of the SARAS MRS platform was conceived as twofold: on one side, it has been tested on specific *technical performance parameters* to be compared with the same ones derived through a commercial robotic surgical system; on the other hand, a *functional validation* was carried out in order to evaluate its performances in actions, and tasks, connected to the surgical practice. The corresponding protocols are detailed in the next paragraphs.

A. Technical Validation

This first part of the validation protocol focused on a *quantitative evaluation* of specific *technical parameters*, collected during the execution of simple dexterity tasks. The aim is to derive an assessment of the SARAS MRS performances in comparison to our reference gold standard robotic platform, *i.e.* the da Vinci® IS 1200 system. The validation tests sessions were held at the ALTAIR Robotics Lab premises (Verona, Italy), where both the robotic systems are available. Four subjects took part to the tests, IT phD students from the ALTAIR lab: three teleoperating SARAS and one the da Vinci®.

Each subject performed two dexterity exercises: namely, the *Point-to-Point* task and the *Follow-a-line* one. Before starting the test session, the subjects had the chance to get acquainted with the system having at disposal 15 minutes, in which freely trying to reproduce the tasks. In the *Point-to-Point* one, the users were asked to move the end effector mounted on the right SARAS arm (a scissor) between two fixed points, called start and target. In the *Follow-a-line* task, the users were requested to follow a semi-circular trajectory with the right SARAS end effector (see Fig. 3). The same tasks were also repeated with the da Vinci® system. Table I summarizes the tests' specifications.

According to [5] [10], the following tasks' parameters have been taken into account for the SARAS performance assessment:

- *Displacement time [s]* (DT): is the average time to perform a complete task;
- *Trajectory length [cm]* (TL): is the length of the instrument's pathway between the starting position and the target/ending position:

$$TL = \int_{t_{\text{start}}}^{t_{\text{target}}} \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2} dt \quad (1)$$

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[5] http://www.medineering.de

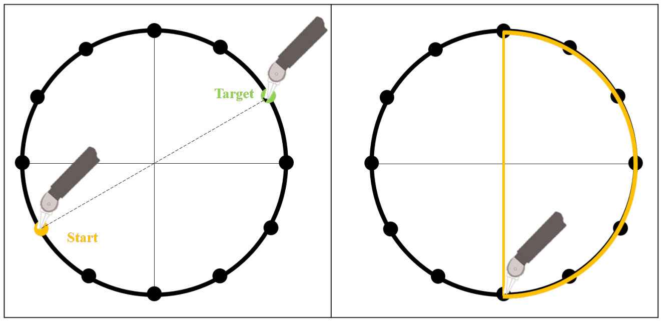

Fig. 3. Technical Validation: Point to Point tasks (*left*) and Follow a line task (*right*).

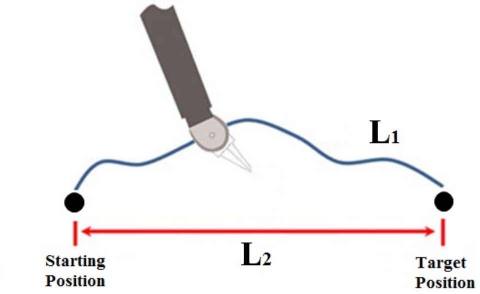

Fig. 4. Exemplification of the Trajectory Redundancy.

where x, y, z are the 3D displacement of x, y and z axes of the SARAS right end-effector;

- *Movement speed [cm/s]* (MS): is the average velocity of movements of the SARAS right robotic end effector during the task;
- *Trajectory redundancy [%]* (TR): is the the ratio of the actual distance to the linear distance. L_1 is the distance covered by the end effector and L_2 represents the linear distances between the starting position and the target position [10]:

$$TR = \frac{L_1}{L_2} \tag{2}$$

  (see Figure 4);
- *Maximum deviation [cm]*: is an indicator of the precision with which the end effector follows the expected trajectory. It is evaluated as the mean of the maximum deviations between the real and expected trajectories;
- *Precision in completing the task [cm]*: is an indicator of the precision with which the end effector reaches the start and target points. It is evaluated as the mean of the maximum deviations between the real and expected coordinates of the two points.

B. Functional Validation

The second part of the validation protocol aimed at evaluating the effectiveness of the SARAS MRS platform in executing surgical-related tasks, on two different levels: *(i)* the ability to accomplish cooperative exercises (i.e. between one arm of SARAS and one of the da Vinci®), which are preparatory to the surgical practice, and *(ii)* the effectiveness in allowing the execution of a simulated surgical procedure. In the first case, in fact, the exercises to be evaluated are inspired by the tasks normally used during training curricula for surgeons to acquire specific skills for L-MIS or R-MIS [18] [19]. This specific sub-part of the protocol is going to be referred, from now on, as *Quantitative Functional validation*. In the second one, instead, the RARP procedure has been specifically modeled [12] and simplified [8] in order to cover the key passages of the surgical practice and demonstrate the feasibility of the cooperation between the two robotic platforms. This last piece of validation is going to be referred as *Qualitative Functional validation*, as it aims at evaluating SARAS performances in a qualitative way, relying on the feedback from expert surgeons who have experienced it on the following topics: *(i)* the perceived satisfaction in tele-operating SARAS, and *(ii)* the coordination and cooperation between the surgeons using the two robotic platforms.

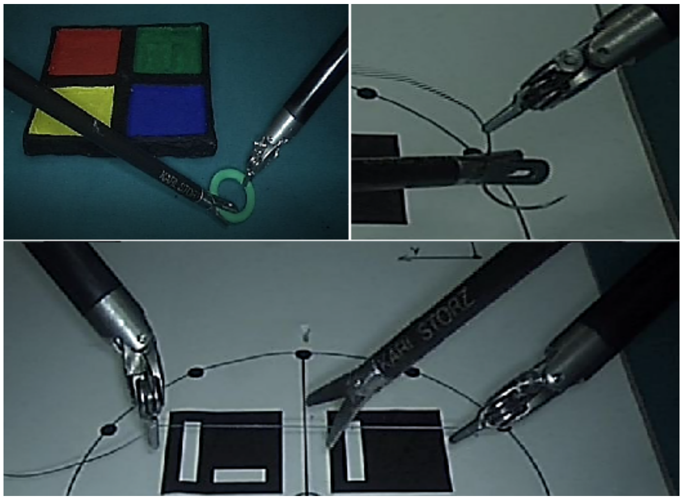

Fig. 5. Quantitative Functional Validation: Goal and Ring (*top left*) task, Needle Grasping (*top right*) task and Thread Cutting task.

1) Quantitative Functional Validation:

as for the Technical Validation, these functional tests were held at the ALTAIR lab in Verona, with four operators of the SARAS MSR platform. The experimental procedure was also similar: after a familiarization period, the subjects performed the *Goal and Ring* task, the *Needle Grasping* task and the *Thread Cutting* task (see Figure 5). The first consists in passing a colored ring from the right da Vinci® arm to the left SARAS one, and placing it in a square of the corresponding color. The second asks for grasping a surgical needle, maintained in position by the right da Vinci® arm, with a grasper held by the left SARAS arm. The third requires to cut a surgical thread, maintained in position by the left and right da Vinci® arms, with a scissor held by the right SARAS arm. For the tests' specifications, please look at Table I.

The following evaluation parameters have been taken into account:

- *Overall task's Success Rate [%]* (OSR): is the number of times in which the final goal of the task is achieved. In our cases, the coloured ring is put in the corresponding

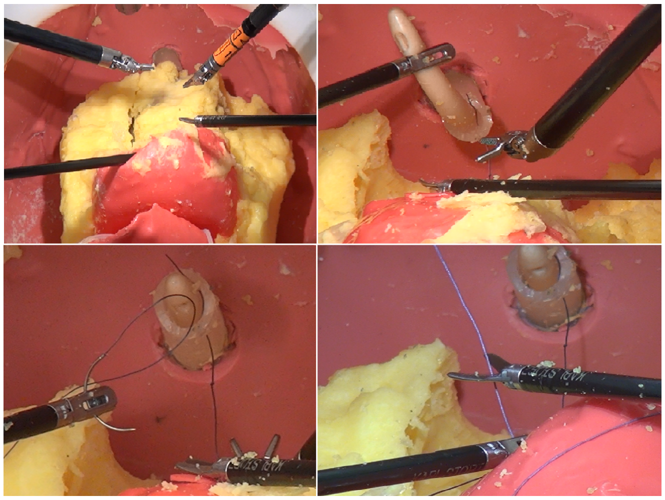

Fig. 6. Qualitative Functional Validation of four key surgical action of the assistant: traction of the bladder (*top left*), grasping of the catheter (*top right*), needle holding (*bottom left*) and thread cutting (*bottom right*).

box, the thread is cut and the needle is grasped;

- *sub-task's Success Rate [%]* (sSR): represents the success rate in performing the collaborative sub-tasks preceding the final goal actuation. In our cases: the passage of the ring between the two robotics arms in the Goal and Ring task, the positioning of the grasper near to the needle and the positioning of the scissor near to the thread in the Needle Grasping and Thread Cutting tasks respectively.

2) *Qualitative Functional Validation:* At the ALTAIR premises, on the basis of [20], two urological surgeons experienced in R-MIS (capable to perform both the first surgeons and assistants tasks) have been involved in the evaluation. A brief pre-test questionnaire has been sketched in order to characterize the participating sample. To familiarize with the SARAS teleoperation system, all the surgeons had the possibility to use SARAS up to 30 minutes and performing simple exercises, e.g. the Goal and Ring one. Then, with the surgeons alternating in the roles of the first operator and the assistant, four key steps of RARP simplified procedure (see Table 1, [8]) have been reproduced, putting particular attention to the execution of the corresponding assistant's surgical actions: i.e. traction and holding of the bladder, grasping of the catheter, needle holding and thread cutting (see Figure 6). At the end of this conclusive part of the protocol, each surgeon completed several questionnaires[6] specifically developed for this validation: *(i)* the Quality Assessment Questionnaire (QAQ), *(ii)* the Usability Survey (US) and *(iii)* the Communication and Coordination Questionnaire (CCQ).

IV. RESULTS

A. Technical Validation

Table II and III provide the overview of the technical performances of the two robotic platforms during the simple dexterity exercises. For every parameter the means and standard deviations per user are reported, as well as the overall mean performance of the SARAS users' group. Please note that for the *Follow-a-line* task the Precision is not reported as, in this case, it corresponds to the Maximum deviation.

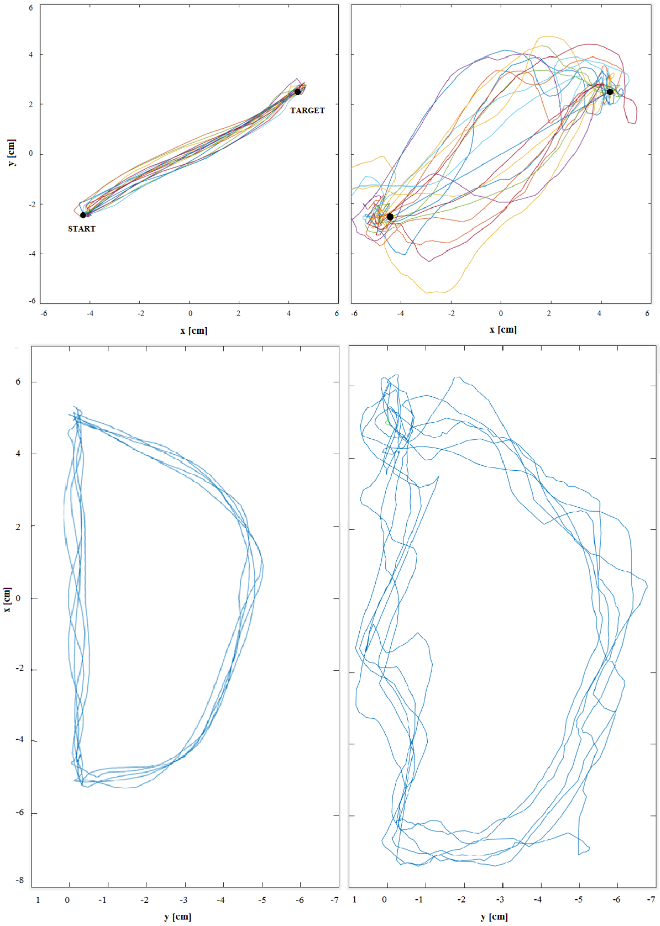

Fig. 7. Example of movement trajectories for Point to Point task (*top*) and Follow a line task (*bottom*) with da Vinci® right arm (*left*) and SARAS right arm (*right*) .

B. Functional Validation

1) *Quantitative Functional Validation:* Table IV presents a summary view of the results obtained for this part of the validation. For each tasks, the mean performances per SARAS user and the corresponding overall mean on the experimental group are reported.

2) *Qualitative Functional Validation:* On the basis of the pre-test questionnaire, we can say that the two surgeons had the same level of expertise for L-MIS (in the 1-50 range of L-MIS surgeries for both), but SURG01 was more experienced in R-MIS than SURG02 (SURG01 numerically has about twice the R-MIS interventions of SURG02). Surgeons' answers to the Qualitative Assessment and Usability questionnaires were rated on a 5-point likert scale, both numerical (1-5, with 5 as maximum score) and alphabetic (A-E, with E as maximum agreement). Tables V and VI report the results of these investigations; regarding the usability the evaluation has been re-scaled on a numerical likert scale (i.e.: A=1, B=2, etc.).

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[6] All the questionnaires are available at the following link: https://saras-project.eu/wp-content/uploads/2019/11/Functional-Validation-Questionnaires.pdf

TABLE I
TECHNICAL AND FUNCTIONAL TASKS' SPECIFICATIONS.

Task	SARAS Users	da Vinci® Users	# of tasks/user
Point to Point	3	1	60
Follow a line	3	1	15
Goal and Ring	4	0	23
Needle grasping	4	0	20
Thread cutting	4	0	20

TABLE II
RESULTS OF THE TECHNICAL VALIDATION - *Point-to-Point*: MEANS AND (STANDARD DEVIATIONS).

Task Metrics	da Vinci® User	SARAS User1	SARAS User2	SARAS User3	SARAS Mean
Displacement time [s]	3.05 (.91)	6.57 (2.35)	7.33 (2.32)	5.62 (1.65)	**6.51 (2.23)**
Trajectory length [cm]	10.94 (.57)	16.04 (3.55)	18.51 (3.41)	16.02 (3.37)	**16.86 (3.62)**
Movement speed [cm/s]	3.85 (.94)	2.60 (.48)	2.61 (.58)	2.93 (.47)	**2.71 (.53)**
Trajectory redundancy [%]	109.4 (5.72)	161.53 (36.60)	185.14 (34.08)	160.23 (33.67)	**168.96 (36.47)**
Max Deviation [cm]	0.5 (.15)	2.38 (.76)	2.65 (1.01)	2.58 (.84)	**2.54 (.88)**
Precision [cm]	0.21 (.12)	0.44 (.25)	0.55 (.38)	0.52 (.40)	**0.50 (.35)**

TABLE III
RESULTS OF THE TECHNICAL VALIDATION - *Follow-a-line*: MEANS AND (STANDARD DEVIATIONS).

Task Metrics	da Vinci® User	SARAS User1	SARAS User2	SARAS User3	SARAS Mean
Displacement time [s]	9.64 (2.86)	16.16 (2.18)	15.29 (3.47)	17.63 (3.41)	**16.36 (3.16)**
Trajectory length [cm]	26.32 (.39)	43.86 (7.49)	45.53 (7.26)	39.31 (4.92)	**42.90 (7.03)**
Movement speed [cm/s]	2.85 (.83)	2.73 (.41)	3.03 (.43)	2.08 (.37)	**2.62 (.56)**
Trajectory redundancy [%]	102.40 (1.53)	170.59 (29.14)	177.12 (28.25)	152.92 (19.13)	**166.88 (27.34)**
Max Deviation [cm]	1.84 (.16)	3.10 (.70)	3.88 (1.18)	3.58 (.98)	**3.52 (1.00)**

Concluding, the coordination and communication evaluations are summarised in Table VII.

V. DISCUSSIONS OF THE RESULTS

A. Technical Validation

Considering the overview of the tasks' metrics of the two robotic platforms, reported in Table II and III, we can generally assess that SARAS is less performing than the da Vinci® standard (as expected, being a prototype). More precisely, the SARAS MRS platform takes longer to complete the tasks (i.e. the mean SARAS DTs are approximately doubled respect to the da Vinci® ones), describing a more articulated and therefore longer (SARAS TRs and TLs are one and a half, or twice, times the da Vinci® ones) trajectory as it can be noted in Figure 7, but remaining proportionally faster than the da Vinci® platform. These factors translates into a less precision in the execution of the task (please see the corresponding values of Maximum deviation and Precision for the two tasks).

B. Functional Validation

1) Quantitative Functional Validation: With reference to Table IV, in general we observe that the OSR is fully achieved, for each tasks' repetition by all the users, with exeception of User3. Therefore, the SARAS MRS platform seems suitable to reproduce surgical-training-inspired exercises with a good confidence. Different is the case of the sub-tasks success rates (sSR), which rate lower scores, i.e. in a range varying between roughly 60% and 90%, with a higher variability within subjects (see Table IV). On this point, it is worth noting that the sub-tasks considered have a higher degree of difficulty respect to the overall goal of the exercise. In fact, they imply a tight coordination between the arms of the two robotic platforms. Being the SARAS MRS platform a prototype, certainly influences the collaboration between the two end effectors. In particular, the stability of the instrument (tremor) and a difficult depth perception have been reported by the users as the main challenges in the execution of the

TABLE IV
RESULTS OF QUANTITATIVE FUNCTIONAL VALIDATION - MEANS AND (STANDARD DEVIATIONS).

Task	**User1**		**User2**		**User3**		**User4**		**Users Mean**	
	OSR [%]	**sSR [%]**	**OSR [%]**	**sSR [%]**	**OSR [%]**	**sSR [%]**	**OSR [%]**	**sSR [%]**	**OSR [%]**	**sSR [%]**
Goal and Ring	100	67 (36.51)	100	81 (30.58)	67	83 (40.82)	100	67 (31.18)	**92 (16.67)**	**74 (8.89)**
Needle Grasping	100	75 (35.36)	100	62 (36.13)	100	29 (13.31)	100	90 (22.36)	**100**	**64 (26.00)**
Thread Cutting	100	90 (22.36)	100	80 (27.39)	100	90 (22.36)	100	90 (22.36)	**100**	**88 (5.00)**

TABLE V
QUALITATIVE ASSESSMENT QUESTIONNAIRE (QAQ) RESULTS

Code	**Q1. Instruments Handling**	**Q2. Spatial awareness**	**Q3. Time and Motion**	**Q4. Depth Perception**	**Q5. Bimanual dexterity**	**Q6. Efficiency**	**Q7. Sensitivity**	**Q8. Moves Accuracy**	**Q9. Placement Accuracy**	**Q10. Speed**
SURG01	4	4	4	2	3	3	2	4	4	3
SURG02	3	3	2	3	3	3	3	2	3	2
Mean (dev.st)	3.5 (.71)	3.5 (.71)	3 (1.41)	2.5 (.71)	3	3	2.5 (.71)	3 (1.41)	3.5 (.71)	2.5 (.71)

TABLE VI
USABILITY SURVEY (US) RESULTS

Code	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**
SURG01	4	3	4	3	4	2	2	2	3	3	2	4	3	4
SURG02	4	3	3	4	3	3	2	3	3	3	3	3	2	3
Mean (dev.st)	4	3	3.5 (.71)	3.5 (.71)	3.5 (.71)	2.5 (.71)	2	2.5 (.71)	3	3	2.5 (.71)	3.5 (.71)	2.5 (.71)	3.5 (.71)

sub-tasks.

2) Qualitative Functional Validation: As it could be noted from Tables V and VI, the overall quality of the experience in tele-operating SARAS is quite positive (i.e. rated with a 3-upward scoring) for both the surgeons. However, from the QAQ and Usability questionnaires, it emerges that the major difficulty faced by both the users is related to the depth perception of the working space (QAQ-Q4 and US-Q7). This could be caused by the currently lack of virtual fixtures in the SARAS system, i.e. the overlay of virtual sensory information on the visualised work-space, in order to increase the perception, and therefore the performance, during a tele-manipulation task. The misleading depth perception is reflected into other low-scores feed backs from the surgeons, closely related to it, which however are centered around different aspects. SURG01, the most experienced in R-MIS, asks for improvements in the visual equipment, due to the absence of a guidance support (e.g. additional information overlay); while SURG02 reports a low performance in the movements economy and accuracy.

VI. CONCLUSIONS AND FUTURE PERSPECTIVES

In this paper we present the validation protocol framed for the evaluation of a new master-slave robotic system, the SARAS MRS platform. It is intended to be operated by the assistant surgeon during R-MIS and, therefore, to cooperate with a commercial da Vinci® surgical system. The validation has been carried out in order to assess the SARAS performances from both a technical- and a surgical-related perspective. In the former case, it was evaluated in its motion-related parameters (e.g. trajectory length, motion speed, etc.) while executing simple dexterity tasks. In the latter, it was analysed in its capability to fulfill surgical training-inspired tasks and while simulating some critical passages of an elective R-MIS procedure on synthetic human abdomen phantom models: a simplified RARP. The results obtained describe a prototype with reasonably lower performances than the reference da Vinci® IS1200 standard, where the most important aspects to be improved are: the stability of movements of the end effectors and the depth perception. In addition, it is interesting to note that the urologic surgeons, who took part to the protocol, suggested an improvement of the visual equipment, to be possibly enriched with specific virtual fixture to gain a more effective response of the system status. The research on this new MRS platform, although with performances that are not comparable to the current surgical standard, is cardinal and preliminary to the development of a new SARAS surgical robotic platform, which aims at carrying out autonomously

TABLE VII
RESULTS OF THE COMMUNICATION QUESTIONNAIRE - 1 TO 5 LIKERT SCALE, WITH 5 MAXIMUM SCORE

Topics	**SURG01**		**SURG02**	
	Main	**Assistant**	**Main**	**Assistant**
Communication skills	4	4	4	4
I was able to communicate effectively	3	4	4	4
I felt the first/assistant surgeon able to understand my questions and comments	4	4	4	4
I felt comfortable in communicating with the assistant/first surgeon from my telesurgery location	4	4	4	4
I was able to clearly hear remote clinical communications	4	4	4	4

the assistants tasks during both L-MIS and R-MIS procedures. To this purpose, a new ground-breaking Artificial Intelligence (AI) module will be implemented and fed by both an *a priori medical knowledge* (as described in [12]) and a *real intra-operative* one, consisting in procedural data gathered through multiple simulated surgeries with the SARAS MRS platfom.

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