Preliminary Validation of an Editable Virtual Reality Simulator for Minimally Invasive Surgical Training

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Abstract. MIS-SIM is a virtual reality (VR) environment designed and developed for the creation of virtual scenarios that can be used to train and acquire basic and advance laparoscopic skills. The environment is composed by a task editor where a content creator design and develop tasks for the simulator to play. Once they are completed, objective metrics are automatically stored and examined in MIS-SIM's server so they can be displayed by an online platform. The project was validated in Semmelweis University in Budapest, Hungary where an experienced professor designed tasks for 16 young surgeons (PGY 3-4-5) from different surgical fields (gynaecology, general-, plastic-, vascular-, thoracic-, neurosurgery, etc.) with different experiences in laparoscopy. Each participant fulfilled each task as if they were completing them on physical simulator.

Keywords: Virtual reality · Surgical training · MIS-SIM · Personalization

1 Introduction

Virtual reality (VR) is nowadays established as a useful and valid tool to train minimally invasive surgical technical skills [1–3]. Like box trainers, they allow for deliberate practice of technical skills in patient-free environments, with the added value of task repeatability and capability of representing complex scenarios. In addition, computer simulations can determine the level of competence of a surgeon before operating a patient by analysing objective data generated during the simulation.

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If the actions and behaviours the user need to do in virtual environments are implemented correctly, VR can reinforce 3D-orientation, hand-eye coordination, instrument handling or improving the perception of stiffness in surgery for avoiding the fulcrum effect [6]. However, current systems restrict usage to tasks and modules offered, without possibility of personalization. When new procedures appear for training a determined skill, new simulators must be created for them. There are no simulator editors where not only tasks can be created but the behaviours of each object in those tasks be defined.

In this study we present the preliminary validation of the new virtual reality paradigm for minimally invasive surgical training: Minimally Invasive Surgery Simulator (MIS-SIM) scenario editor. MIS-SIM is designed and developed to fill an existing gap in the market: an editor can be used to create, edit and train with personalized virtual tasks and scenarios designed for surgical training.

2 Materials and Methods

2.1 MIS-SIM Environment

MIS-SIM is a multiplatform environment developed to facilitate the creation of virtual tasks for laparoscopic skills training with a custom built-in editor [2]. MIS-SIM follows the logic of physical box trainers where a collection of simple actions is used for training different skills used in laparoscopic surgery [2]. If box trainer's exercises are analysed, each action is done by an object in relation to other (Fig. 1). A task is understood as a sequence of actions between objects. Any object that makes an action in relation to other is called active. The objects that receive the action performed by the active object are called passive. If they do not perform any action on relation to other object, they are considered as regular objects.

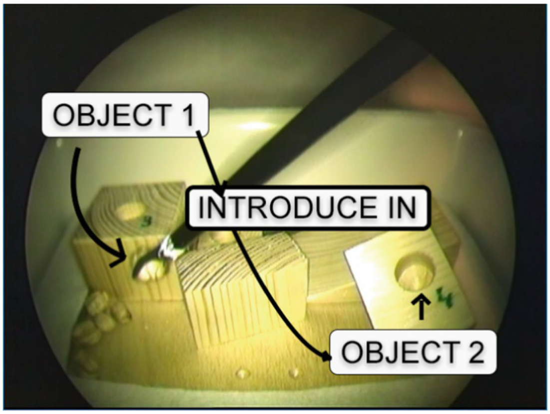

Fig. 1. Box trainer exercise where the user must introduce a ball in a specific hole. Object 1 is active. Object 2 is passive. "Introduce In" is the action.

MIS-SIM's editor displays a 3D scene where regular, active and passive objects are placed by clicking in the resource's browser. Content creators can include as many objects as needed and relate them with the desired actions. Objects have physics simulation based on AABB colliders and rigid bodies belonging to Nvidia Physics Engine [7]. Depending on the object, the collider could be a box, sphere, capsule or a collider with the form of the object's mesh. The objects in the scene can be movable (dynamic) or not (static) depending on the task and the defined behaviours. A dynamic object is an object that can be movable in a 3D scene. On the other hand, a static object is fixed to a determined position and rotation. For example, if the task consists in introducing a ball in a bottle, the bottle should be static as its movement is not needed.

MIS-SIM owns a custom server where tasks can be uploaded and downloaded if the user has internet connection. This allow users access requiring only the software itself and an internet connection to start any simulation the trainer has prepared. Likewise, content creators and teachers may access the editor and create/upload tasks anywhere, for example, from their own home. If a task is not behaving as desired, it can be modified anytime, anywhere.

Once a task is created, each object's behaviours (movement, dragging, physics…) are simulated in play-mode. The simulation can be performed by just clicking the Play button and connecting the input device to the computer. As MIS-SIM is created with a multiplatform engine, it can use any C# compatible haptic device as input.

After performance of each task, metric objective data are collected and automatically uploaded to MIS-SIM's server. These data can be used for exhaustive monitoring of trainees' laparoscopic skills without the need of the supervision of a trained surgeon.

2.2 Preliminary Validation

A testing course was given at Universidad Politécnica de Madrid, Spain in September 2018, where a group of experimented surgeons from Semmelweis University (Hungary) and Leiden University Medical Center (The Netherlands) could test MIS-SIM via streaming. They were able to create and modify tasks. Later, they could test them using a haptic device. Thus, they were able to create and modify tasks. Later, they could test them using their own haptic device.

In February 2019, a preliminary course was carried out as part of a three-hour preparatory course at the Department of Surgical Research and Techniques of Semmelweis University in Budapest, Hungary, to validate if MIS-SIM could be used for improving students' laparoscopic skills. The course was imparted by an experienced professor of Semmelweis University to a small group of residents (PGY 3-4-5) from diverse surgical fields (gynaecology, general-, plastic-, vascular-, thoracic-, neurosurgery, etc.) with different degrees of experience in laparoscopy. The students (participants) were used to box trainer exercises, but they had never used VR simulators. Tests were performed on a PC linked to the haptic device.

Prior to the course, the professor replicated 4 box trainer exercises [5] with the built-in editor based on the type of actions allowed in those exercises (Table 1). At the time of the validation, only 4 type of tasks were allowed: Touch, Introduce In, Pass Through and Join. Each task belongs to a group of one of these actions or a combination of some of them.

Table 1. Exercises based on actions

Task type by action	Descriptions	Objective	Metrics
Touch (Fig. 1A)	Touch tasks are created under the premise that an object with physics colliders enters or at least touches another object's hit collider	– Touch objects in relation to other – Move an object to a determined place	– 2 min as max. time to solve the task – 30 s as objective time to solve the task – 1–6 objectives per task – Floor and walls were not considered as an error – Dragging Time, average velocity and distance – No shadows – Number of errors – Description of how to solve them
Introduce In (Fig. 1B)	Introduce-In tasks are created based on regular box trainer simulators where an object like a ball or a tube is introduced in a bar or a bottle. The passive objects (where other objects are introduced) are static for better performance and more accuracy. If the task has more than one object, the student must introduce it in one place and then change it to another	– Introduce an object inside another	– 4 min as max. time to solve the task – 2 min as objective time to solve the task – 3 objectives per task – Floor and walls were not considered as an error – Dragging Time, average velocity and distance – No shadows – Number of errors – Description of how to solve them

(*continued*)

Table 1. (*continued*)

Task type by action	Descriptions	Objective	Metrics
Pass Through (Fig. 1C)	Pass-Through tasks are created with a defined path that the student must follow in order without touching the loops or letting any of the objects fall to the ground	– Pass an object through predefined objects	– 10 min as max. time to solve the task – 5 min as objective time to solve the task – 3 objectives per task – Floor and walls were not considered as an error – Dragging Time, average velocity and distance – No shadows – Number of errors – Description of how to solve them
Join (Fig. 1D)	Join tasks are similar to Introduce-in tasks, but in this case one rubber object had to connect two passive objects	– Join 2 parts of an object to two different objects, joining those two by the active object	– 4 min as max. time to solve the task – 2 min as objective time to solve the task – 3 objectives per task – Floor and walls were not considered as an error – Dragging Time, average velocity and distance – No shadows – Number of errors – Description of how to solve them

Every participant had to complete all tasks once. They did not practice before performing any of the tasks, but nevertheless they could see how the other residents completed the tasks. After each realization MIS-SIM automatically calculated objective metrics on performance (Table 2). Metric data were stored in an encrypted JSON file that was stored in the performance computer locally.

Once all the participants completed each task, they could create new tasks and modify the previous ones so that other participants could solve them one by one in the same way the previous tasks were performed. The students defined the new description, metrics, and settings about how to solve their versions of the tasks based on the

Table 2. Metrics defined in the actions within the validation

Metric name	Description
Description	Detailed description about how to solve a specific task
Max. time	Maximum time to complete the task
Time	Time spent doing the task
Errors	Mistakes produced by the participants
Grab time	Time spent grabbing the different objects
Collisions	Collision detection. How to
Dragging settings	Dragging time, velocity and distance of each object
Sensibility	Sensibility
Depth	Camera rendering shadows for better depth perception

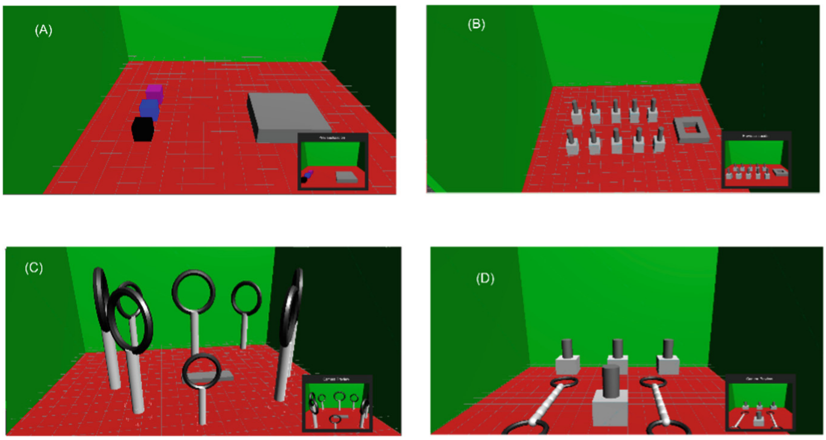

Fig. 2. Exercises based on the actions. **(A):** In this specific task the student had to hold the blue cube with one grasper while moving the other two to the top of the grey flat cube. **(B):** In this specific task the student had to introduce the prism with a hole in some poles avoiding the others. **(C):** In this specific task the student had to follow the path of loops, passing through them with the prism of the centre. The starting loop did not matter but all of them needed to be completed clockwise. **(D):** In this specific task the student had to connect each loop of the elastic bands to their corresponding poles in specific order.

different actions allowed in the task. Four of them were action-only (just one action) but with more than one objective with the same action (Fig. 2). The students explained to the others what they should do and then saved those tasks in the computer and then run them so that other participants could test them with the haptic device in play-mode. At the end, an informal interview was carried out with them to gather feedback and impressions on its usefulness and usability.

3 Results

The professor first tested in vivo the editor and the play-mode to show how easy could be to configure a new task and how to test them in front of the participants (Fig. 3). When completing the created task, he explained how to solve it to reinforce the already given instructions.

Fig. 3. Professor showing how to use MIS-SIM's environment.

Sixteen participants of the Budapest course tested the MIS-SIM environment. None of the participants had troubles completing the tasks with two hands. However, as they had to complete the tasks one by one watching how other students completed them and following the professor's instructions. Then, all of them were interviewed about the usability and what they thought that could be improvable for a surgical trainee.

In the interviews, the professor described MIS-SIM as powerful, but found difficultness in its use given the high number of more than required customization options. On the other hand, the students, found MIS-SIM professional, easy to use and enjoyable. The built-in editor allows the user to modify all the needed properties for most of the possibilities, but it demands them to set those correctly. Some of the participants, and even the professor first forgot to setup correctly the metrics and non-desired behaviours appeared when performing some of the tasks. They also did not set-up correctly the camera in some of the introduce-in tasks and when trying to perform them, some of the objects were far enough to not reach them with the grasper. To solve this, they went back to the editor, modify those tasks and retry the performance again. They found this kind of trial and error annoying but regular in similar 3D Editors like 3Ds Max or Blender.

Some of the obtained feedback was about the feeling when grabbing object with the graspers and how their meshes are adapted to the different objects placed in the 3D space when grabbing them. As there was no force feedback returned by the haptic device, they only had visual feedback given when performing the grabbing. At first, the virtual graspers adapted to the form of the draggable meshes when grabbing them, so a more realistic visual effect was achieved, but the participants complained about being able to close completely the haptic scissor without visual feedback in the virtual world. Thus, this feature was removed and when closing the scissor, the virtual grasper closed completely passing through draggable objects. All the participants preferred this but complained about not having force-feedback with the haptic when grabbing objects. This, however, did not affect task completion.

The generated data about the realization of each task was saved locally in the computer used by the participants to solve each of the objectives, However, if those data were uploaded to MIS-SIM's server, they could be visualized in MIS-SIM's online platform where a graph displayed based on the results. This way, the professor can follow the progress of each student and what are their lacks.

4 Conclusions

MIS-SIM aspires to break the barrier between VR and medical education by empowering users to create their own tasks. Thus, MIS-SIM improves creativity and generates objective data that can be followed for testing new procedures and virtual technology in virtual reality environments designed for improving minimally invasive skills. For most of the participants, laparoscopy is an important part of their speciality, thus the acquired skills during the course are going to be essential in their future work.

Feedback received by users within the preliminary validation shows the potential of MIS-SIM to (1) create personalised medical learning contents tailored to preferred learning styles, allowing the creation of individualize learning paths and (2) improve the efficiency of training by focusing on the training needs of the learners.

The challenges we face in the next months include the streamlining the user interface and functionalities to make the environment accessible and user friendly to teachers and content creators. Once these improvements are completed, we are confident of the benefits of this new paradigm based on personalized VR training. Moreover, we believe that this could be exported to other medical specialities.

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