

Evaluation of the Virtual Mirror as a Navigational Aid for Augmented Reality Driven Minimally Invasive Procedures

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ABSTRACT

The paper presents a user study investigating perceptual effects of a virtual mirror being used as a tangible interactive tool in a medical Augmented Reality scenario. In particular, we evaluated whether an additional perspective provided by the virtual mirror supports instrument guidance in terms of precision and straightness. 31 participants were asked to navigate an endoscopic instrument in a simulated minimally invasive port setting. Results show a significant higher precision of instrument guidance when a virtual mirror provides additional views of the target region.

Index Terms: H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: Interaction styles—Evaluation/Methodology

1 INTRODUCTION

Researchers have identified the perceptive advantage of integrating the visualization of medical imaging data such as US [1, 10], CT [18, 4] or MRI [7] into the field of view of the surgeon using AR technology. Different hardware interfaces have been used to enable such augmented views of the operation site, for example optical see-through head mounted displays (HMD) [16, 3, 22, 11], video see-through HMDs [17, 1], virtual windows [19, 5] or endoscope cameras [6]. However, one of the reasons for the absence of AR technology in today's operating rooms (OR) might be the deficient interaction of surgeons with visualized 3D data to get all desired views of the region of interest.

"Magic lenses" [13] have been proposed to discover hidden structures, which are presented distinctively compared to the objects laying outside the field of the lens. Alternatively, the visualization of 3D information can be locally changed. Lenses provide additional functional views, however, they do not allow for additional geometric perspectives to entirely explore 3D data from all sides.

When observing the AR scene with head worn AR systems such as HMDs, simply changing the view position by walking around the patient becomes impractical. Space around the operating table in the OR is usually extremely scarce due to further surgical staff and all kind of equipment. Views from beneath the operating table onto the registered medical data is not possible at all and repositioning the patient is no option. Classical interaction methods for transformation parameters known from 2D interfaces can not be applied anymore. In this case, the advantage of presenting imaging data registered with the patient would lapse and mental mapping of image information with the real anatomy is again necessary.

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To allow intuitive interaction with and observation of virtual objects with having only one or a few points of view on the AR scene, we take advantage of an interaction paradigm, which is strongly used in our everyday life, however novel for AR applications. We introduce an interactively guided Virtual Mirror for generating additional views from any desired perspectives on the virtual part of an AR scene [14].

2 VIRTUAL MIRRORS AS PART OF AR SCENES

Virtual Mirrors can become an intuitive interactive device for many applications in the field of Augmented Reality. Overall, we identified four important benefits for Virtual Mirrors in AR scenarios.

- 1. Visually accessing visually restricted areas:** Whenever a virtual object can not be viewed completely because the observer's viewpoint is visually restricted from a region of interest, the Virtual Mirror can provide the desired perspective.
- 2. Supporting navigational tasks:** The Virtual Mirror is not restricted by physical barriers. For this reason, it can enter for instance the patient's body to provide helpful additional views for navigational tasks in several intra-operative procedures.
- 3. Understanding complex structures:** Whenever a complex 3D structure can be observed from only a few points of stereo or monocular views for analytical or navigational tasks, a Virtual Mirror is capable of integrating additional perspectives on that structure into the original view. This can help to better understand hidden or self occluding structures such as complex blood vessel trees.
- 4. Improving depth perception:** Simple superimposition of virtual anatomy on the patient or on organs inside the patient results in misleading depth perception of involved objects. Virtual anatomy seems to be located outside the patient's body or the organ surface. A tangible Virtual Mirror with the mirror image reacting on user interaction is capable of communicating information about relative and absolute positions of affected objects.

2.1 Perception of Reflection

Reflection is a function of the perceiver's viewpoint and the position and characteristics of the reflective object.

The most common reflective objects in our daily life are mirrors supporting us in navigation and observation tasks. Mirrors provide us with an additional perspective on regions of interest for fast decision making in traffic situations, to support hand-eye coordination for shaving the beard, or for exploring physically restricted areas like the oral cavity during dental treatment.

The combination of visual information from a mirror image and the observer's viewpoint results in an impressively enriching information about the order of the objects. Figure 1 shows two similar looking objects and a plane that can be changed to become reflective. The presented scene is in fact a variation of the earlier introduced ball-in-box scenario used to show the effectiveness of

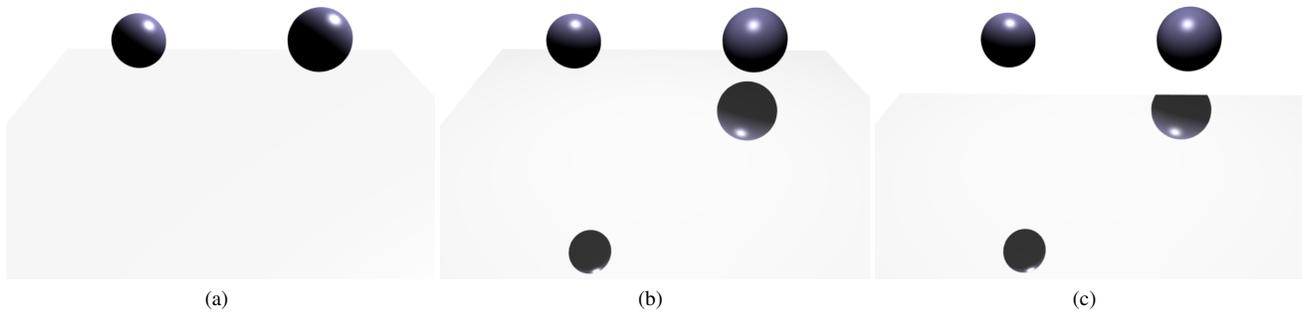


Figure 1: Modified virtual ball-in-box scenario to distinguish the importance of reflection for spatial perception [9, 12]. Without the mirror ground plane the bigger object seems to be located nearer due to the depth cue *relative size*. The presence of reflection can correct the depth order. Reflections provide the perceiver with additional perspectives to entirely explore an object or a structure of objects.

shadows for depth perception [9, 12]. The objects have the same color but not the same size. Due to the depth cue *relative size*, the right ball in figure 1(a) would be perceived closer than the left one. However, the reflective ground plane reveals the true position of the objects as shown in figure 1(b). Also the borders of the mirror plane that cut off the mirror image help to locate the objects (see Fig. 1(c)).

When motion comes into play, the interactively repositioned mirror provides even stronger depth cues due to visual feedback in the changing reflected image. *Motion parallax* or *motion perspective* can support the perception when the observer moves either his head or the mirror. Also *interposition* contributes to perception of depth when the visualization partially occludes the mirror plane. As an advantage over shadows, the projection of an object onto a reflective area allows for viewing physically hidden or occluded areas. An example from the real world is the dentist's mirror to explore areas inside the oral cavity of the patient which are not directly visible.

Further materials within our natural environment show reflections that are intuitively perceived such as water surfaces, glass or metal planes. It is much more difficult to derive exact spatial relation between the reflecting object and the reflected one than with mirrors, however, some rough cues are still available as shown in figure 2.

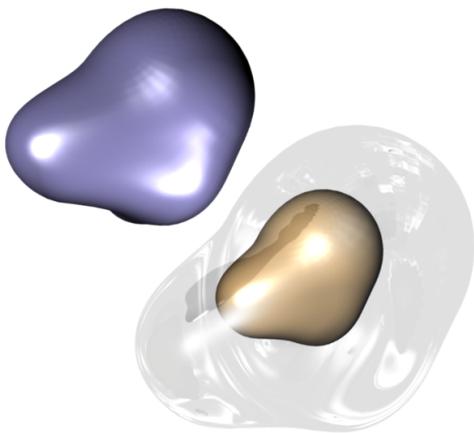


Figure 2: Reflective material in our natural environment provides cues for spatially relating objects to each other.

2.2 Studying the Benefit of Virtual Mirrors for Medical Applications

In 2006, the concept and prototype of the virtual mirror has been presented for the first time. It can be guided through an AR scene by a hand-held, tracked, remote mouse pointer. The mirror was successfully tested with a phantom, a cadaver, and a patient. At that time, however, we have not evaluated its usefulness for any kind of application [2].

This first generation of the virtual mirror has been presented to 20 surgeons within the scope of an earlier study [20] that assessed the perception of different methods of in-situ visualization. Physicians proposed several applications to support surgical procedures supposed that the AR system will become part of their working environment.

They suggested using the additional perspective to better understand 3D structures in diagnostics such as fracture pattern, border structures and entire vertebral segments. They further mentioned that the mirror might also help in navigational tasks for instance the position control of implants, all kind of osteotomy close to nerves and vessels, control of the resection plane and resection border for tumor and metastases surgery, placement of osteosynthesis materials and prostheses, control of screw length, pose of drill canals and positioning screws, and get side views in general when an instrument approaches orthogradly.

The stated benefits **visually accessing physically restricted areas** and **understanding complex structures** have been addressed in [2]. In this case a laparoscopic camera captures the video images, which are augmented with 3D angiographic images and then presented on a monitor.

The evaluation presented in section 3.2 shall further investigate the advantage of the Virtual Mirror for **improving depth perception** and **supporting navigational tasks** in medical AR scenarios. For this reason, we designed an abstract task that is performed at a simulated minimally invasive interface to the operation site. In this case, the AR scene is presented with the HMD based system described in 3.1. Figures 1(a) and 1(b) let assume that a Virtual Mirror can improve depth perception of objects within the field of view. This assumption is supposed to be evaluated with the present study. Regarding the benefit of a mirror for navigation tasks, we believe that errors can be avoided or at least they can be early detected and quickly corrected. Although the additional view provided by the mirror may be advantageous for perception and navigation issues, interpretation of the mirror image and identification of its benefit for the task may consume some time.

With respect to these assumptions we have the following hypotheses:

1. Hypothesis 1: A Virtual Mirror enables higher precision in navigational tasks.
2. Hypothesis 2: A Virtual Mirror helps the early detection and correction of erroneous navigation.
3. Hypothesis 3: A Virtual Mirror can improve depth perception and enables therefore a more determined navigation.
4. Hypothesis 4: A Virtual Mirror will increase time of navigation.

3 METHOD

We will first describe the used AR system and then introduce our study design.

3.1 Video See-Through Head Mounted Display

The main components of the present AR system are the video see-through head mounted display (HMD) (see Fig. 3), an outside-in tracking system and the CAMPAR software framework.

To locate tracking targets with our working space, for example surgical instruments, we use an optical outside-in tracking system (A.R.T GmbH, Weilheim, Germany) with four infrared cameras fixed to the ceiling covering a large working area (3x3x2 m). In this case sensor cameras are rigidly fixed for observing the tracking volume. They receive signals sent from markers attached to tracking bodies. After an initial calibration procedure the outside-in tracking system provides accurate tracking as long as the tracking cameras remain at their position. The system is capable of tracking the targets in our setup with an accuracy of $< 0.35[mm]$ RMS. The tracking system uses retro-reflective fiducial markers. To recover the six degrees of freedom of a rigid body, the external optical tracking system requires at least three rigidly attached markers. Fiducial markers are attached to the surgical instruments or the phantom/patient.

The AR scene is presented to the user by the RAMP system consisting of tracking software and a stereo video see-through head mounted display presented by Sauer et al. [18]. For superior registration quality, we combine and synchronize the outside-in tracking system with a inside out-tracking system that is part of the RAMP system. The single camera inside-out tracking system allows for a high rotational precision [8] necessary for tracking the stereoscopic video see-through HMD. In this case, the sensors are attached to the body to be located, e.g. the HMD, while receiving and measuring signals from external senders. Two color cameras rigidly attached to the HMD simulate the eye's view. An additional infrared camera, mounted on the HMD, realizes inside-out tracking. This infrared camera tracks a reference frame, which is a static set of retro-reflective markers, to estimate the head pose for the registration of both the virtual and the real world. The reference frame enables the transition between the inside-out and the outside-in tracking systems since both tracking systems calculate the same coordinate system for the reference frame.

All augmentations on targets, which are tracked by the optical outside-in tracking system, have to be positioned respectively to the reference frame of the inside-out tracking system. The following equation calculates the transformation H_{ref}^t from the reference frame to an exemplary target (H_{from}^{to}):

$$H_{ref}^t = H_{ext}^t * (H_{ext}^{ref})^{-1} \quad (1)$$

Transformations H_{ext}^t and H_{ext}^{ref} are provided by the external, optical outside-in tracking system. The former describes the transformation respective to the origin of the tracking system to a target; the latter one is the transformation from the origin of the tracking system to the marker frame for inside-out tracking.

Within the experiment setup of our user study, we track an endoscopic instrument and an aluminum frame simulating the operation site.

We use the AR software framework CAMPAR that provides methods for incorporation of tracking data, synchronization of data inputs and registration, image processing and visualization of medical volume data such as CT or MRI using different rendering techniques [21].

A PC based computer is used to render 3D graphics, to compute and include tracking data, to synchronize and combine imagery of virtual and real entities. The specification is Intel Xeon(TM), CPU 3.20 GHz, 1,80 GB RAM, NVIDIA Quadro FX 3400/4400. The Virtual Mirror and further computer graphic objects are implemented in C++ using OpenGL¹.

3.2 Study Design

The experimental setup simulates an operation area, which is typical for minimally invasive spine or liver procedures (see Figure 3). During such interventions, surgeons usually view only a small area of the patient's skin, which is bordered by covers to secure the sterility of the operation site. Within the sterile area, different trocars are penetrated through the skin and offer ports to the interior anatomy of the patient.

3.2.1 The Test Bed

The test bed consists of an aluminum frame that is covered with elastic synthetic leather to simulate the skin surface (see Figure 3). The leather is masked with surgical covers usually used for real operations. In the center of the masked skin area, we installed one trocar serving as the port to the backside of the skin, i.e. to the inside of the patient. The frame is positioned on a table and tracked by the outside-in tracking system, which is described in [2]. Participants



Figure 3: Subjects have to insert an endoscopic instrument through the trocar within the simulated operating area.

are seated in front of the aluminum frame. This reduces their freedom of movement [15] and simulates the situation in the OR when the surgeon's space is restricted by further clinical staff and equipment. However, subjects can still move the upper part of their body, head and thorax, to get different views.

3.2.2 The Task

We instructed participants to penetrate a tracked endoscopic instrument through the mentioned trocar (see Figure 3) and showed figures 4 to explain the AR system and the task. Participants received the following information:

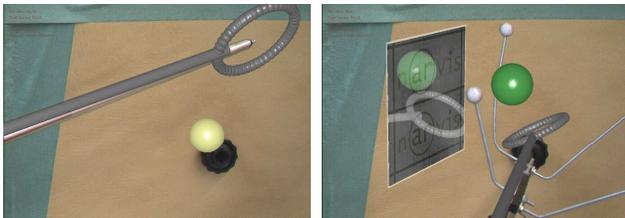
¹<http://www.opengl.org>

The instrument is augmented with a virtual cylinder aligned with the instrument body and a virtual ring at its tip. In addition, the virtual part of the AR scene consists of twenty virtual green balls, only one displayed at the same time. Each ball has an individual position behind the frame and represents one of twenty tasks that have to be fulfilled. This task requires the user to move the virtual ring over the augmented green ball without touching it. The green ball changes its color to blue when it collides with the ring. To release the collision state in order to restart and finish the task, one has to move the ring away from the ball until it is green again (distance \geq diameter of the ball). Once the ring has been successfully guided over the green ball without any collisions, the green ball disappears and a start button (see yellow ball in Figure 4(a)) is drawn at a fixed location close to the trocar. One can individually decide when they want to continue with the next ball by touching the start button with the ring. For each subject ten of the twenty balls are visualized together with a Virtual Mirror that is positioned at a suitable location that has been individually defined for each green ball. Figures 4(a) show the AR scene and are presented to the subjects before the experiment started. The presence/absence of the Virtual Mirror is the only independent variable that was switched for each new candidate. The balls, each having an individual index, differ in size and position and therefore show different levels of difficulty. For this reason, we changed the index order for each new candidate.

The study design does not include practice trails prior to the experiment. As soon as participants wear the HMD, they can see the virtually augmented instrument. However, no initial try runs are planned that would allow insertion of the instrument through the trocar and interaction with virtual balls.

3.2.3 Measuring Data Acquisition

Every time, when the start button is touched, we start measuring the number of collisions (NC), number of tries (NT), average duration of collisions for each task (DC), duration of each task (DT), path length of the tip of the tracked instrument for each task (PL) and motion of the instrument along its axes for each task, which we call depth motion (DL). The latter two items are measured from tracking data of the instrument that is recorded while the subject is performing.



(a) Start button

(b) Target ball and the Virtual Mirror

Figure 4: The left image shows the yellow start button that has to be touched to continue the task. In the right figure the virtual instrument and the green ball is reflected to provide additional perspectives during the performance.

During first tests with the experimental setup, we noticed that moving the instrument rapidly through the scene in order to estimate the relative positions from the intersection of the virtual ring and the balls is much easier than using the mirror reflection as the primary depth cue. However, if the ball was a tumor inside an organ, picking around the target region could seriously damage the surrounding tissue. A deep seated tumor inside an organ can sometimes not be physically accessed at all with the instrument and no virtual intersection giving visual feedback can be achieved. For this

reason, we instructed participants to avoid collisions: *Faultless performance is preferred over trial and error strategies.*

DL and PL are supposed to investigate, how straight forward the task can be accomplished. We assume that if subjects follow the trial and error strategy and move the ring close to the ball, they notice very late that they will fail. In this situation they will collide or almost collide with the sphere. In any case they have to bring the ring in a save position next to the ball and start a new approach, which is measured with NT.

The present test bed takes the advantage of the AR specific problem of misleading depth perception. Using the naive approach of in-situ visualization, the virtual anatomy occludes the real skin. For this reason, the virtual anatomy seems to be outside the body. We try to disable as many natural depth cues as possible to negotiate the perceptive effect of a Virtual Mirror in an AR scene. The depth cue *occlusion* among real and virtual objects is ineffective, since virtual balls behind the leather cover occlude the simulated skin. Since position and size of the balls change, also the depth cue *relative size* does not provide perceptive hints. *Familiar size* has no effect because the spheres are not textured or do not correspond to known objects. *Motion parallax* is restricted by placing the subject on the chair. The depth cue *stereopsis*, which is ranked as one of the most powerful information sources for depth perception is available in every situation during the task due to the stereo HMD.

The resulting AR scene has very little depth information to estimate the position and depth of the green balls, which allows us to reduce the falsification of data analysis caused by other visual cues than the Virtual Mirror. We consider DL as a strong indicator for depth perception. DL measures the ability of the participant to guide the tip of the instrument to the same depth level as the target object, a green ball. Back and forward motion of the instrument along its axes through the port would increase DL.

With respect to the previously stated hypotheses, we assume that the presence of the Virtual Mirror will reduce NC and NT because the additional perspective allows for side views to control the relative position of the ring and the balls and for a more determined and direct navigation of the instrument. We further assume that participants will need more time to complete one task when using the Virtual Mirror (DT). Subjects may feel motivated to use this additional information source for their task to avoid errors. However, understanding the reflection, learning to interact with the Virtual Mirror and double checking of the ring position in the reflection image will consume some time. With the additional perspective due to the Virtual Mirror DC will be reduced. Deep or unnoticed collisions costing time like complete penetration of the instrument into the ball can be rather avoided and reduce duration of collision. DC is computed for each navigation mode and each participant as follows:

$$\frac{\sum_{i=1}^n t_i}{\sum_{i=1}^n NC_i} \quad (2)$$

where t_i measures how long the ring has collided with the ball in one of $n = 10$ tasks. NC_i is the number of collisions in one of $n = 10$ tasks. For this reason, DC measures the average time per collision of one participant.

After the practical task of the experiment, we ask the participants to fill out an online questionnaire consisting of standardized questions (scale 0-4: *I strongly agree — I agree — I am undecided — I disagree — I strongly disagree*) and open questions. The questions were posed in German, which is the native language of most of the subjects. Participants can complete the survey either on a computer in the same room as the experiment takes place or they are provided with a link and a password to complete the survey when they have time.

We invited 31 participants to participate our study. The result and feedback of the first three candidates were used to optimize the experimental setting. We then evaluated the performance of 17 female and 11 male participants (N=28). The average age is $M = 29.26$ years ($SD = 4.53$). Although medical background or anatomic knowledge is not required to participate in the study, 10 subjects (5 female, 5 male) are surgeons or medical students at the trauma surgery department, Klinikum Innenstadt, LMU Muenchen, Germany. Voluntary participants were not compensated in any form for their participation in the study.

4 RESULTS

On the significance level of $\alpha = .05$ the Kolmogorov-Smirnov-test indicates a normal distribution of all samples except PL with present Virtual Mirror. In order to take the differing experience with the instrumentation and vision abilities of participants into account, the one-tailed t-test for paired samples has been chosen to test the hypotheses stated above. When analyzing the correlation of at least ordinally scaled data the one-tailed, bivariate correlation analysis (SPEARMAN) has been used. For cardinally scaled data, the one-tailed, bivariate correlation analysis (PEARSON) has been chosen.

Table 1 shows the descriptive statistics of samples.

The measuring data shows that the subjects need some time to get used to the system and the task. The learning curves (see figures 5 and 6) when analyzing DT and NC show that subjects quickly attune to the tasks.

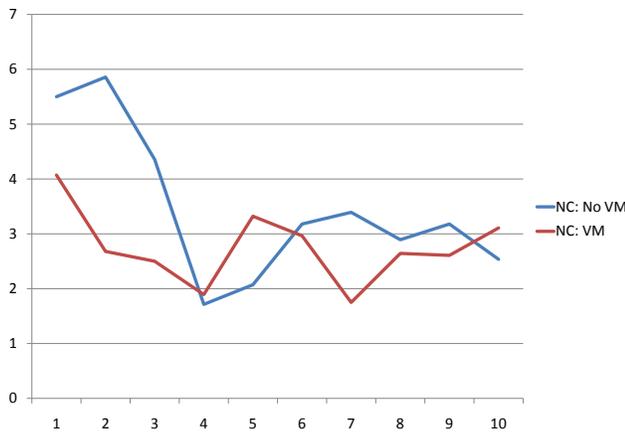


Figure 5: Line diagram shows mean number of collisions (NC) with increasing experience when fulfilling the tasks with present Virtual Mirror (VM) and absent Virtual Mirror (No VM).

Table 1: Statistics of all measured data (N=28): Number of Collisions (NC), Number of Tries (NT), Duration of Task (DT), Duration of Collision (DC), Path length (PL), Path length in depth direction (DL).

	With Virtual Mirror M(SD)	Without Virtual Mirror M(SD)
NC (count)	2.75(2.18)	3.47(3.11)
NT (count)	3.41(1.59)	3.8(2.27)
DT (sec)	30.101(21.47)	26.178(18.43)
DC (sec)	0.45(0.11)	0.47(0.31)
PL (mm)	1583.28(1460.82)	1432.34(924.28)
DL (mm)	737.81 (647.65)	692.61(446.61)

The test indicates significant less collisions with the balls (NC)

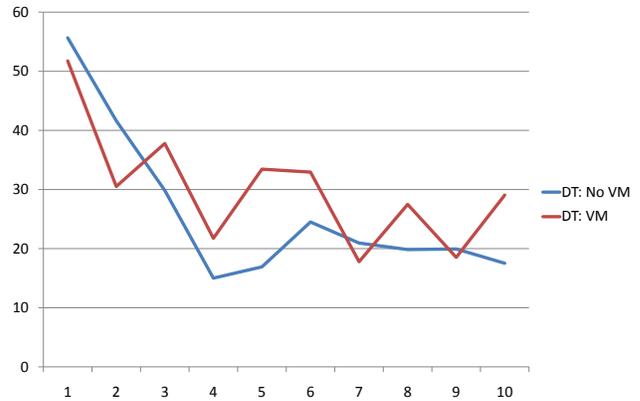


Figure 6: Line diagram shows mean time performance (DT) with increasing experience when fulfilling the tasks with present Virtual Mirror (VM) and absent Virtual Mirror (No VM).

when performing with a present Virtual Mirror ($t(27) = 2.062$, $p \leq .05$). This confirms our first hypothesis that the additional perspective due to the mirror image allows for more accurate navigation in AR environments.

Unexpectedly, data (DC) does not show that a present mirror helps to early detect and correct of erroneous navigation ($t(26) = 0.254$, $p \geq .05$). For this reason, the second hypothesis can not be confirmed.

The analysis of DL, which is our main criteria to investigate the potentials of Virtual Mirrors for improving depth perception, cannot confirm our third hypothesis and leads to the acceptance of H_0 ($t(27) = -0.401$, $p \geq .05$). Also PL is not influenced by a present Virtual Mirror ($p \geq .05$) (WILCOXON) and leads to the conclusion that the mirror does not support the navigator to work more straight forward.

Unexpectedly, no effect due the Virtual Mirror can be shown when analyzing the time of performance ($t(27) = -1.156$, $p \geq .05$). This let us conclude, that the understanding and analysis of the mirror reflection to be used for the navigational tasks does not negatively affect the time of performance.

While one participant is performing, investigators can observe the AR views of subjects on monitors. We noticed a difference in the performance comparing subjects with and without medical background regarding the smoothness and cautiousness of motion (see also Figure 7).

Further exploratory data analysis shows that medical expertise significantly correlates with NC for both navigation modes and with DT without mirror. The correlation of all measured samples can be reviewed in table 2.

The results of the questionnaire are given as means and standard deviation.

- More than half of the sample (54.8%) *strongly agreed* or *agreed* that they had problems to perceive the position of the green spheres. 25.8% were undecided on this question ($M = 1.61$, $SD = 0.84$).
- 63.3% *strongly disagreed* or *disagreed* that the Virtual Mirror is not beneficial for the performance of the task ($M = 2.7$, $SD = 1.05$).
- More than 80.6% *strongly disagreed* or *disagreed* that the mirror was not hindering the performance of the task ($M = 3.26$, $SD = 0.93$).

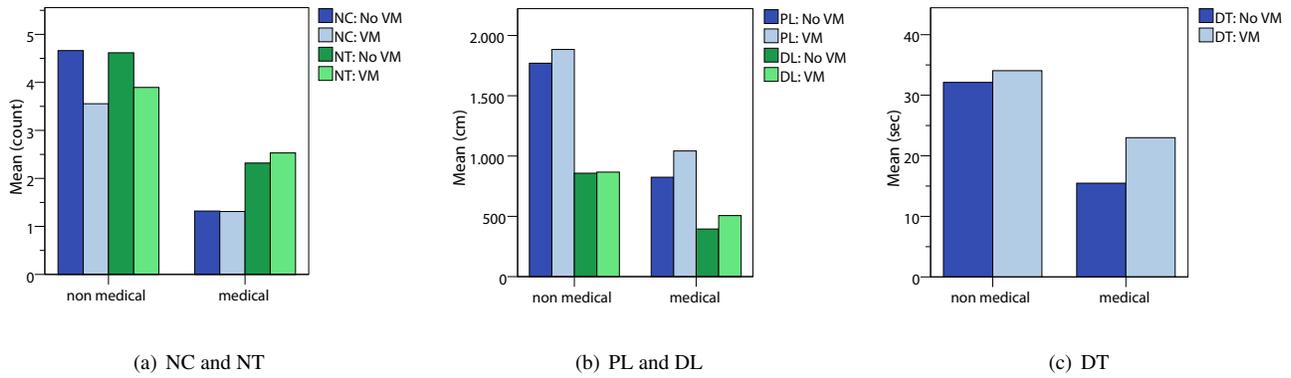


Figure 7: Diagrams show mean performance grouped in present Virtual Mirror (VM) and absent Virtual Mirror (No VM) as well as participants having medical background or not.

Table 2: Correlation of medical expertise (medical background coded as 1, no medical background coded as 0) and samples: Number of Collisions (NC), Number of Tries (NT), Duration of Task (DT), Duration of Collision (DC), Path length (PL), Path length in depth direction (DL).

	With Virtual Mirror		Without Virtual Mirror	
	r	p	r	p
NC	-.503	≤ .05	-.525	≤ .05
NT	-.420	≤ .05	-.494	≤ .05
DT	-.251	≥ .05	-.440	≤ .05
DC	.317	≤ .05	-.078	≥ .05
LP	-.281	≥ .05	-.499	≤ .05
DL	-.272	≥ .05	-.506	≤ .05

- 51.7% *strongly agreed* or *agreed* that they used the Virtual Mirror if available for the task. 19.4 % were *undecided* if they used the Mirror (M = 1.68, SD = 1.28).
- 64.4% *strongly agreed* or *agreed* that the Virtual Mirror would be more beneficial, if they can position it manually. 25.8% were *undecided* (M = 2.32, SD = 0.832).

Regarding different subtasks of one task

- 54.8% *strongly agreed* or *agreed* that the Virtual Mirror was helpful for the navigation of the instrument tip **to** the sphere (M = 1.58, SD = 1.12).
- 63.5% *strongly agreed* or *agreed* that the Virtual Mirror was helpful for the navigation of the ring **over** the sphere (M = 1.32, SD = 1.05).
- 51.6% *strongly agreed* or *agreed* that the Virtual Mirror was helpful to avoid collisions (M = 1.52, SD = 1.12).
- 77.4% *strongly agreed* or *agreed* that the Virtual Mirror was helpful to control the position of objects due to the additional perspective (M = 1.23, SD = 0.85).
- 61.3% *strongly agreed* or *agreed* that they felt safer when navigating with the Virtual Mirror. 22.6 % were *undecided* (M = 1.25, SD = 0.99).

We asked the subjects to propose ideas that can improve the navigational task. They suggested adding shadow effects, digits telling the distance to the target object, acoustic feedback and the use of several mirrors.

5 DISCUSSION AND INTERPRETATION

NC is considered as the most important variable that indicates high precision of performance. Statistical analysis has shown significant less collisions of the ring with the balls when having the Virtual Mirror as a navigational aid at hand. Figure 4 lets assume that the Virtual Mirror provides in particular at the beginning more accurate performance while NC of both visualization modes tends to converge in later steps. This indicates the importance of a follow up study investigating the learning curve and long term performance.

Figures 1 assume a positive effect of mirror reflection on the correct estimation of depth order and even relative distances of objects. Unexpectedly, DL being considered as the most important indication for depth perception has not shown an improvement when adding the Virtual Mirror to the scene. Longer average pathways of the tip in three dimensions and along the instrument axes when the Virtual Mirror is present (not significant) even let us assume that its presence rather negatively affects depth perception. During the experiments, we observed that some of the participants experimented with the mirror reflection in order to negotiate the most promising position and trajectory of the ring before they started with the actual tasks. In fact, after those participants had finished all tasks, some of them claimed that they needed some time to get used to the Virtual Mirror and explore its advantage. Once they have learned how to use the mirror reflection, they found it beneficial. Interestingly, the Virtual Mirror had no effect on the time of performance (DT). Others mentioned that they had difficulties at the beginning to interact with the Virtual Mirror, which decreased their motivation for further exploration of its potential navigational advantage. In those cases, subjects reported that they decided not to use the mirror for accomplishing the remaining tasks.

Inspired by the present AR scene, one subject proposed an interesting idea on how to design a similar system for tumor resection. He suggested attaching a virtual semi-transparent sphere to the tip of the instrument. The color and transparency of that sphere can be coded with the distance and relative orientation to the target region. A virtual sphere would not injure real tissue surrounding the tumor, however, it can be used as a visual park distance control system to safely guide the instrument to the pathological tissue.

The experiment modes are not uniformly distributed within the two groups having different medical expertise. For this reason, we have to postpone the evaluation of performance regarding the expertise to future studies.

When we briefed participants, we did not ask them to follow a certain performance strategy such as *working fast* or *working accurate*. We rather tried to sensitize them to the highly critical surgical task and the unacceptance of a previously described trial and error performance strategy. This can be seen as an indirect

suggestion to give priority to accuracy rather than speed. With this strategy, we minimize our influence on the participant's natural performance. This allows us to measure his or her individual motor skills in combination with a navigational aid in terms of time and accuracy.

In fact, some of the subjects guided the instrument slowly and carefully through the scene with a strong focus on accurate work, i.e. avoiding collisions and finishing with the first try. Others seemed to have missed our initial suggestion and rather followed the tail and error strategy.

We have to be entirely sure whether participants missed, ignored or forgot (e.g. due to nervousness) our suggestion or if assessed data simply reflects the participant's motor abilities. For this reason, in follow up studies we will ask subjects about their motivation while performing in a subsequent questionnaire.

The motivation to work accurately can also be increased by reactive feedback of the program due to the performance of the subject. For instance, acoustic feedback like beep sounds with increasing frequency similar to those used for announcing vital signs in the OR can produce stress when the subject fails. In addition, we will test two groups separately according to their medical expertise and compare their data.

In future experiments, we plan to qualify collisions. It is interesting whether the ball was only touched slightly or the ring completely penetrated the ball. In order to evaluate the frequency of using the Virtual Mirror if present, we plan to measure the view direction of subjects. This tells us where the subjects looked at and how often the mirror reflection is used.

The reason for the predefined position of the mirror is that we want to provide similar test conditions for every new subject without evaluating their capabilities of handling two instruments at the same time. However, some of the subjects mentioned that it would be preferable to reposition or reorient the mirror to a more helpful location. We believe that in a real scenario the mirror can be a virtual add-on feature for an instrument.

6 CONCLUSION

The paper presents a user study that assessed the effect of a virtual mirror being part of a medical Augmented Reality scene. In particular, we were interested whether the additional view on the region of interaction in a minimally invasive surgery setting may result in better depth perception of augmented objects and in higher precision of performance. Statistics of 31 participants show that an endoscopic instrument can be navigated more accurately through a simulated minimally invasive port setting to a designated area of interest. However, analysis of measured data that is supposed to assess the quality of depth perception of the scene did not confirm our hypothesis.

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