Development and evaluation of a virtual reality patient simulation (VRPS)

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ABSTRACT

In disasters and mass casualty incidents (MCIs) paramedics initially determine the severeness of all patients' injuries during the so-called triage. In order to enhance disaster preparedness continuous training of all paramedics is indispensable. Due to the fact that large disaster control exercises are laborious and expensive, additional training on a small scale makes sense. Therefore we designed and developed a virtual reality patient simulation (VRPS) to train paramedics in this disaster triage. The presented approach includes gesture based interactions with the virtual patients in order to simulate the triage process as realistically as possible.

The evaluated approach focuses on the training of paramedics in disaster triage according to the mSTaRT (modified Simple Triage and Rapid Treatment) triage algorithm on a multi-touch table top device. At the Munich fire department fully-qualified paramedics performed 160 triage processes with the triage simulation. The accuracy of the triage processes was compared to previous disaster control exercises with real mimes. The presented results of this explorative evaluation will be the basis for future, larger evaluations.

Keywords

VR User Interfaces, Graphical user interfaces, Disaster triage, Training and simulation

1. INTRODUCTION

In disasters and mass casualty incidents (MCIs) paramedics have to perform numerous tasks, which are regularly trained in disaster control exercises. These tasks include establishing organizational structures, diagnosing all involved patients, medicating the patients according to their injuries and transporting them to hospitals. Affected patients expect receiving medication and being transported to the hospital quickly. Usually there are not enough paramedics available to treat all injured patients at once. Therefore during the so-called triage, the paramedics initially determine the severeness of all patients' injuries. In order to guarantee all patients a fair and equal treatment, the triage may not exceed 45 seconds per patient and the paramedics perform clearly defined procedures, e.g. the mSTaRT (modified Simple Triage and Rapid Treatment) algorithm. When triaging on the basis of mSTaRT, the paramedics examine the patient regarding the following vital parameters: ability to walk, fatal injuries, breathing rate, peripheral pulse, spurt bleedings and consciousness [Kan06].

According to these vital parameters the patients are classified in four categories: *T1 (immediate care)*, *T2 (urgent care)*, *T3 (delayed care)* and *Deceased (no care)* [Bak07]. The paramedics do not start the medication before the triage of all patients is finished. The order of the medication is derived from the triage categories. First of all the *T1 (red)* patients are medicated and transported to hospital if required. Afterward the *T2 (yellow)* and *T3 (green)* patients are medicated. To increase the chances of survival of all affected patients, an accurate and prompt triage of all patients is of utmost importance. The overestimation of the patient's injuries (*overtriage*) is inaccurate, as well as the underestimation of the patient's injuries (*undertriage*). The so-called *critical overtriage* is the *T1* classification of patients who do not need immediate care, the *critical undertriage* is the wrong classification of patients who need immediate care [Gut06]. The aim is to decrease the *overtriage* rates as well as the *undertriage* rates, therefore paramedics are regularly trained in disaster control exercises.

In this paper we give a short motivation for the development of the VRPS, continuing with a short overview on related work. Afterwards we explain our patient model, our patient patterns and gesture based interactions which are the basis of the VRPS. Finally we present the evaluation design and the evaluation results.

2. MOTIVATION

On the one hand frequent disaster control exercises are essential to regularly train the paramedics in accurate and quick triage, on the other hand the organization of disaster control exercises is expensive and time-consuming. For instance, so-called mimes play the role of the patients in a disaster control exercise to make the practical training as realistic as possible. When training in large scale disaster control exercises with a hundred victims, a hundred volunteers are required. Furthermore these mimes have to be masqueraded and instructed during the preparation phase. Due to these organizational challenges smaller triage trainings are arranged additionally to large scale exercises. These trainings concentrate on the triage process and do not include further tasks, such as medication and transportation. The number of different mimes is limited in these trainings; every paramedic performs only about 10 different triage processes [Pro06, Man04].

The introduction of a virtual reality patient simulation (VRPS) gives rise to the possibility to combine the advantages of both exercise types. A VRPS is highly scalable while at the same time the preparation phase is short. By using a multi-touch table top interface instead of a desktop based computer, intuitive interaction metaphors can be applied. Instead of performing WIMP (window, icon, menu, pointer) based interactions [Eng68, Gre91], the paramedic can use both hands and manipulate the simulated patient directly. Due to the fact that the technical implementation has already been published previously [Nes07], the focus of this paper is the development of such a VRPS and the evaluation of its usability in a real setting. The interaction on table top interfaces, however, is not as natural as interacting with real mimes. Considering the fact that the focus of a triage exercise is on the general triage process, and not on the acquisition of basic skills (such as taking pulse, checking the breathing or bandaging spurt bleedings), training on a table top is a new and promising possibility. Training on table top interfaces does not replace disaster control exercises, but gives the paramedics the possibility to improve triage skills which are essential in disaster operations.

3. RELATED WORK

Patient simulations for doctors and paramedics have been proposed by different research groups. Saunders et al., for instance, model emergency department operations in a computer simulation [Sau89]. Moenk et al. analyzed the different available patient simulations, in Germany alone about 90 different patient simulations are used for the further training of doctors [Mon99].

Evaluation results of triage processes based on real disaster control exercises were presented by Gutsch et al. [Gut06]. In addition to the evaluation of time aspects (see Table 1) they also evaluated the triage accuracy (see Table 2) and the triage of the critically injured (see Table 3 and 4). Their evaluation bases on the triage of 132 patients, which were triaged by 11 triage teams. The duration of the mSTaRT procedure required 35 seconds in median. Furthermore Gutsch et al. state that fast triage can accelerate medication and transport of injured victims with life threatening conditions [Gut06]. In our evaluation we will compare the results from our VRPS to their results from real life.

Vincent et al. taught mass casualty triage skills by training medical students in a fully immersed three-dimensional VR environment. They found out that the triage skills of untrained students could be improved regarding speed and efficacy [Vin08]. The training of first responders by means of an immersive simulation was performed by Wilkerson et al. Their simulation trains the paramedics in adhering to triage protocols, avoiding overtreatment, communication (interagency, intraagency and scene-to-hospital) and hazards (static and dynamic). Both simulations require extensive technical equipment, this factor results in a substantial higher lead time as opposed to our VRPS.

On the interface side Lee et al. were one of the first who proposed a multi-touch table top interface [Lee85]. The table top interface which is used for the VRPS was inspired by the work of Jeff Han [Han05] and bases on the principle of FTIR (frustrated total internal reflection). This multi-touch interface enables developers to include gesture based interactions in their applications. He found that multi-touch interaction promises great improvements in usability, intuitiveness and efficiency. Additionally multi-touch interfaces facilitate multi-user interactions, because multiple users can easily interact with the computer simultaneously [Han06].

Shen et al. focus on the collaboration aspects when working on horizontal interactive surfaces. Their concepts include the presentation of private and personal information on multi user table top devices in a way that privacy and security is guaranteed [She03]. Furthermore they state that the interaction on a table top is similar to the interaction with paper when collaborating around-the-table. Their vision is that the table has to disappear into and become a part of the human to human interaction. They state, however, that this vision is a big challenge which has not been solved yet [She06].

This brief overview on related work shows that virtual reality simulations are playing an increasingly important role in skill training. Simulations, however, are not identical to events in real life. In fact computer simulations confront the doctors with life-like situations which require their immediate feedback, e.g. decisions and actions. Issenberg et al. furthermore emphasise that simulation technology, which is now gaining wider acceptance in medicine, is already well established in other disciplines [Iss99].

Value	**Reference [Gut06]**	**Table top**
n	132	160
AVG	41s	22s
Minimum	10s	3s
25%-Quantile	25s	12s
50%-Quantile	35s	20s
75%-Quantile	49s	28s
Maximum	121s	71s

Table 1. Time needed in the reference exercise [Gut06] and the table top evaluation

Value	**Reference [Gut06]**	**Table top**
Accurate triage	84.85 %	89.37 %
Overtriage	8.33 %	6.25 %
critically	5.30 %	5.63 %
non-critically	3.03 %	0.62 %
Undertriage	6.82 %	4.38 %
critically	3.03 %	2.50 %
non-critically	3.79 %	1.88 %

Table 2. *Overtriage* and *undertriage* rates of reference evaluation [Gut06] and table top evaluation

4. *PATIENT MODEL* AND *PATIENT PATTERNS*

The aim of the triage is to check all patients' vital functions. For that purpose the paramedics have to interact with the patients. Paramedics, for instance, have to check whether the patient is able to walk. Additionally they have to determine the breathing rate, have to stop serious wounds from bleeding and have to feel for the patient's peripheral pulse. All these interactions influence each other, therefore additionally to an initial patient condition a complete *patient model* is required.

The *patient model* can be represented by a finite state machine (FSM) as shown in Figure 1. The most important state is the *neutral state* in which the VRPS rests when no interaction has been performed recently. Paramedic interactions such as *touch*, *check breathing*, *take pulse*, *check bleeding* and *assign card* temporarily transfer the virtual patient into other states in which the virtual patient exhibits appropriate reactions before returning to the neutral state. The *touch* interaction, for example, will either lead to the state *no reaction* or to the state *reaction*. The transition from the state *reaction* back to the neutral state in this case is performed by a time trigger (for the benefit of clarity the time triggered transitions have been left out in the figure). These interactions may change the condition of the patient and influence the vital functions. For instance patients might breathe again after the removal of foreign bodies from their airways (this interaction is shown in Figure 2).

Depending on the patient position (lying, standing or sitting) different transitions are feasible. It is not possible, for instance, to perform a head tilt - chin lift manoeuvre with standing patients. The different patient positions and the transitions are shown in Figure 3. The same interaction might get a lying patient to stand up or lead to no change due to the fact that the patient is not able to stand up. Therefore this FSM is non deterministic.

Whereas all possible interactions are contained in the *general patient model*, the concrete patient information is contained in a specific *patient pattern*. These patterns contain the information in what way a transition changes the patient's state. Our partners from the fire department Munich have already designed about 300 different *patient patterns*; some of these *patient patterns* have already been transferred to our VRPS.

The extension of the general patient model by specific *patient patterns* leads to an *adapted patient model* which can be represented by a deterministic FSM. When performing a *touch* interaction, the adapted automaton either always changes to the state *reaction* or always changes to the state *no reaction*. Only the deterministic behaviour of the simulated patients guarantees the reproducibility of triage trainings.

Some transitions, however, still influence other transitions. As a consequence, the underlying deterministic FSM is getting more complex than the non-deterministic one as shown in Figure 4. Before the foreign body has been removed, the *breathing* transition leads from the initial state *Z0* to the *no breathing* state (the dotted transition to the *breathing* state has been removed in this *adapted patient model*). After the removal of the foreign body, the *breathing* transition leads from the state *Z0** (which uses the same visualization as the initial state *Z0*) to the *breathing* state. The paramedic, however, is not able to distinguish between state *Z0** and *Z0*, therefore from his point of view the system does not seem to be deterministic.

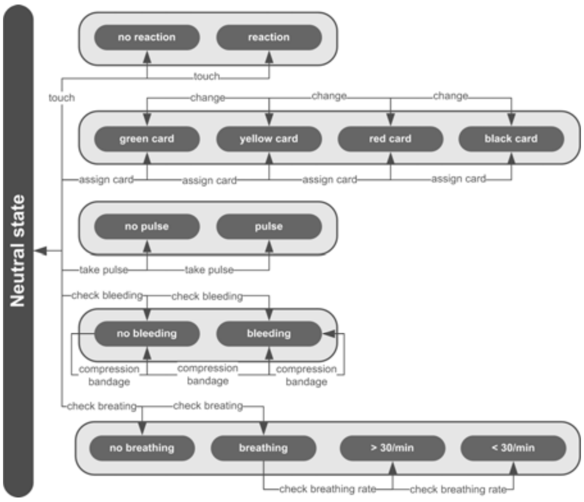

Figure 1. The *patient model*

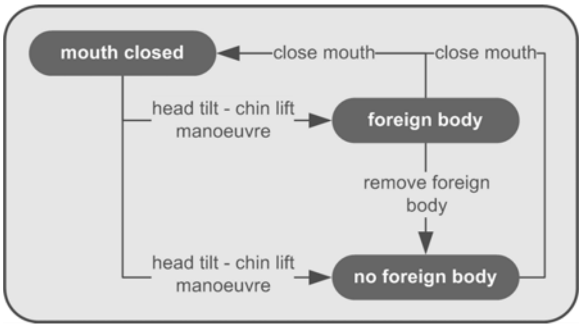

Figure 2. Removing foreign bodies

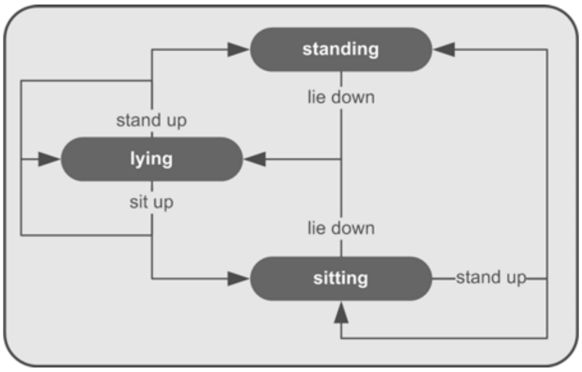

Figure 3. Changing the patient position

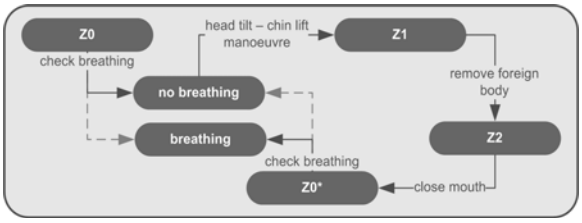

Figure 4. Deterministic FSM of an *advanced patient model*

5. GESTURE BASED INTERACTION

The examination of all patients' vital parameters (ability to walk, fatal injuries, breathing rate, peripheral pulse, spurt bleedings and consciousness) are performed by gestures on the table top interface. Additionally bandages can be pressed on spurt and non-spurt bleedings and a colored triage tag can be attached to the patient. Not all these interactions make sense in a disaster triage. Pressing bandages on non-spurt bleedings, for instance, is not required [Kan06]. Furthermore counting out the patients breathing rate or checking his peripheral pulse is not necessary if the patient is able to walk. Nevertheless in the triage simulation these interactions can also be performed in order to give the paramedics the possibility to make mistakes and learn from them, similar to a real exercise. In order to achieve a realistic simulation, the time for all gestures in the VRPS correlates to the time needed in reality. This correlation was worked out by the Munich fire department.

In Figure 5 and 6 the gesture for the change of the patient's position is shown (the underlying *patient model* is shown in Figure 3). The paramedic helps the patient up by touching both his shoulders as shown in Figure 5 and helps him down by touching them again as shown in Figure 6. Helping standing patients down is generally not reasonable during the disaster triage, the reason for offering the paramedics this interaction anyhow is the same as mentioned above. The red boxes illustrate the sensitive areas for this gesture. During the training, however, they were naturally not visible for the triaging paramedic as shown in Figure 7.

Figure 5. Propping the patient up

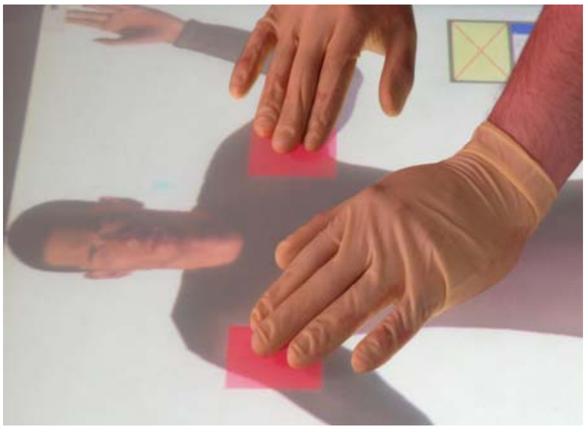

Figure 6. Lying the patient down

6. EVALUATION DESIGN

The evaluation design has to consider the fact that usually paramedics perform the disaster triage in teams of two. The triage training on the table top was therefore also performed in triage teams. Due to the fact that we used a multi-touch table top interface, this multi-user requirement could be fulfilled very easily. The function of the triaging paramedic is to interact with the patient and to check his vital functions, whereas the supervising paramedic mainly controls the accuracy of the triage process. Furthermore a basic documentation, a numerical logging of the quantity of patients in every category, is done by the supervising paramedic as shown in Figure 7.

The evaluation was performed with eight paramedics who triaged in four teams (team 1-4). Every paramedic performed 2 trainings with 10 triage processes each. Altogether 160 triage processes have been performed on the table top, and the results can therefore be compared to a previous disaster control exercise with real mimes and 132 triage processes [Gut06]. Due to the fact, that real disaster control exercises are quite laborious and expensive, a between-subject design had to be chosen. The group which participated in our evaluation has an education which is very similar to the education of the group from [Gut06], because of the fact that both groups are from Munich fire department. Therefore we can draw first conclusions in our explorative study, even if our sample size is rather small for a in-between-subject design.

In real disaster control exercises there are no breaks between any triage processes, but the teams usually change their roles within the team. Thus the order of the triage processes was the following: team 1A, team 1B, team 1A, team 1B, team 2A, team 2B, and so on. The first team member (A) triaged 10 patients and was supervised by the second team member (B), after 10 triage processes paramedic B triaged 10 patients and was supervised by paramedic A. All interactions which the paramedics performed on the table top interface were logged and additionally the triage trainings on the table top were recorded by two cameras. One camera focused the table top device and the other one focused on the triage team. Furthermore we used voice recording to document the verbal collaboration between the two paramedics.

7. RESULTS

Due to the fact that the time for each triage process has been logged on the table top, the triage times can be compared to the triage times in the real disaster control exercise as shown in Table 1. The average time for one triage process is nearly half as long as in real disaster control exercises (22s opposed to 41s), and also the median is lower (20s opposed to 35s). In order to simulate all interactions as realistic as possible the table top application uses empirical values for the time need of the different interactions. These were provided by the Munich fire department. They experienced, for instance, that propping up lying patients or counting out the breathing rate takes usually about ten seconds. The evaluation results, however, show that the time needed for these interactions definitely has to be estimated higher. The evaluation is adequate to identify first results and gain a first impression on the usability of this VRPS. For an advanced statistical interpretation, however, a within-subject design has to be used in the next evaluation.

In addition to the time aspects of the triage training, the accuracy of this training is of essential importance as mentioned above. Therefore we compared the *overtriage* and *undertriage* rates evaluated in the table top based training to the results from the disaster control exercise with real mimes as shown in Table 2. The results of both evaluations are quite similar, whereas in the real disaster control exercise about 85 percent of all patients were triaged correct, in the table top training 89 percent of all patients were triaged correct. This difference is too slight to be interpreted statistically due to the between-subject design. On basis of the critically *overtriage* and *undertriage* rates shown in Table 3 the diagnostic effectiveness of the triage processes were compared in Table 4.

reference [Gut06]	**red**$_{\mathbf{patient}}$	**¬red**$_{\mathbf{patient}}$	**sum**
red$_{\mathbf{triage}}$	30	6	36
¬red$_{\mathbf{triage}}$	4	92	96
sum	34	98	132

table top	**red**$_{\mathbf{patient}}$	**¬red**$_{\mathbf{patient}}$	**sum**
red$_{\mathbf{triage}}$	41	9	50
¬red$_{\mathbf{triage}}$	7	103	110
sum	48	112	160

Table 3. *Overtriage* and *undertriage* of the critically injured: The patient state (index *patient*) is compared to the triaged category (index *triage*) and the reference evaluation [Gut06] is compared to the table top evaluation

Figure 7. The virtual reality patient simulation (VRPS) on the multi-touch table top

value	**reference [Gut06]**	**table top**
Se[a]	0.882 (0.73–0.95)	0.854 (0.75–0.95)
Sp[b]	0.939 (0.87–0.97)	0.920 (0.87–0.97)
PPA[c]	0.833 (0.68–0.92)	0.820 (0.71–0.93)
NP[A]	0.958 (0.90–0.98)	0.936 (0.87–1.00)
PL[e]	14.4 (6.6–31.6)	10.63 (5.6–20.1)
NL[f]	0.125 (0.05–0.32)	0.159 (0.08–0.32)

Table 4. Diagnostic effectiveness when triaging the critically injured in reference exercise [Gut06] and table top training

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[a] Sensitivity
[b] Specificity
[c] Positive predictive accuracy
[d] Negative predictive accuracy
[e] Positive Likelihood
[f] Negative Likelihood

8. CONCLUSIONS AND FUTURE WORK

The explorative evaluation results show that the introduction of our VRPS for the triage training does not prevent the paramedics from making inaccurate triage decisions. In order to provide a realistic training it is important, that this possibility does not get lost in the VRPS. Therefore a table top device can be adequate to be used in disaster control exercises. Due to the successful first evaluation we expect that paramedics can train essential skills which are needed in disaster operations, such as disaster triage, on multi-touch table top interfaces in addition to real life triage trainings. More frequent trainings of the paramedics can help to be better prepared for the case of disaster.

The question whether the training effects of a table top training are similar to the training effects of triage training with real mimes has not been considered in this first evaluation, and therefore will be the topic of our future work. We propose to compare three groups of paramedics, the first group trains on the table top, the second one performs no training and the third one trains with real mimes. Afterwards all three groups triage real mimes and the time aspects and triage accuracy are evaluated.

9. ACKNOWLEDGMENTS

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