Design and Development of Virtual Patients

Simon Nestler Andreas Dollinger Florian Echtler Manuel Huber Gudrun Klinker

Technische Universität München
Boltzmannstrasse 3
85748 Garching bei München
(*nestler*|*klinker*)@*in.tum.de*

Abstract: This paper discusses the design and prototypical implementation of virtual patients to train paramedics in disaster operations. These virtual patients are presented on a multi-touch table top. The current approach focuses on disaster triage according to the mSTaRT triage algorithm.
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, training on a small scale makes sense. The presented approach includes gesture based interactions to simulate the patients as realistically as possible. This more intuitive interaction results in a more realistic simulation of the patient and a better preparation for the real situation.

Keywords: Interaction, Simulation, Training, Triage

1 Introduction

Since disasters with large numbers of injured and dead people have occurred in high frequency in the last years, experts increasingly call for further improvements in disaster preparedness [MMA04].

In disasters paramedics cope with numerous tasks, which have to be trained regularly: They establish organizational structures in the early stages of the disaster management process, triage all involved patients in the disaster area and finally medicate the patients according to their injuries which have been classified during the triage. In Munich the triage system has recently been changed. Instead of performing the triage by doctors, a triage algorithm, the mSTaRT[1]-algorithm, is applied by paramedics [KHK+06].

When triaging on the basis of the mSTaRT-algorithm, the paramedics have to perform different actions. First of all the paramedics check whether the patient is able to walk and test the patient for deadly injuries. Afterwards they check the breathing and count out the breathing rate, apply compression bandages on serious bleedings and feel the patient's peripheral pulse. Finally they have to check if the patient is awake and responsive.

This recent introduction of a new triage procedure requires intensive and continuous training. Large disaster control exercises give paramedics the chance to train the triage

[1] modified simple triage and rapid treatment

algorithm with numerous different patients. In the last large scale disaster control exercise in Munich about 2000 people, including exercise actors, paramedics, fire fighters and police officers, were involved.

The so-called exercise actors are playing the role of the disaster victims during the whole disaster control exercise. These actors are painted with heavy make-up during the preparation phase to simulate realistic injuries. Typically they are medical students, hospital nurses or members of emergency medical services. The advantage is, that the specific patient patterns are acted out by them at the best. Furthermore curious onlookers are included in disaster control exercises in order to make the exercises as realistic as possible [PRNP06].

2 Motivation

The organization of disaster control exercises is quite expensive and laborious. Therefore it is not possible to arrange these exercises regularly enough to keep the paramedics in practice.

In addition to large scale disaster control exercises smaller trainings are conducted. In these smaller trainings, however, a very limited number of patient patterns can be trained at once due to the fact that only a few exercise actors are available. Furthermore mainly basic skills are trained in these small trainings.

Computer-based trainings of disaster scenarios incorporate the advantages of both types of disaster control exercises. On the one hand the lead time is quite low, after the boot up of the system the training can be started. On the other hand, as many patient patterns as requested can be trained. Furthermore no exercise actors are needed, all involved paramedics can be trained in disaster management at the same time - assuming that enough training systems are available.

In computer-based trainings not only basic skills but also advanced pre-clinical skills can be trained. Paramedics can work in life-like situations, the simulation is not restricted to the patients, it can be expanded to include also the concrete scenario itself. This is of major importance because the disaster scenario influences all processes performed at the patients. For example, triages after a bomb attack differ significantly from triages after a railway accident.

On multi-touch table top interfaces the paramedics can be trained closer to reality than on conventional desktop computers. The more intuitive interaction results in a more realistic simulation of the patient and a better preparation for the real situation.

It has to be stressed that the simulation on the table top does not have to be more realistic than a disaster control exercise with human actors. In disaster control exercises training artificialities are quite common, e.g. bleedings or lost breathing can not be acted out by the exercise actors and thus are only symbolically indicated. These artificialities may therefore also occur in a computer based triage training.

3 Technical background

The first multi-touch technologies have been invented a couple of decades ago. One of the first technologies was developed by Lee et al. in the year 1985 [LBS85].

Thus far there are no affordable multi-touch interfaces which are fit for mass production. Therefore we have built a multi-touch table top on our own as shown in Figure 1. Our prototypical table top bases on the technology proposed by Han. His approach uses the phenomenon of frustrated total internal reflection (FTIR) and enables robust multi-touch sensing at a minimum of engineering effort and expense [Han05].

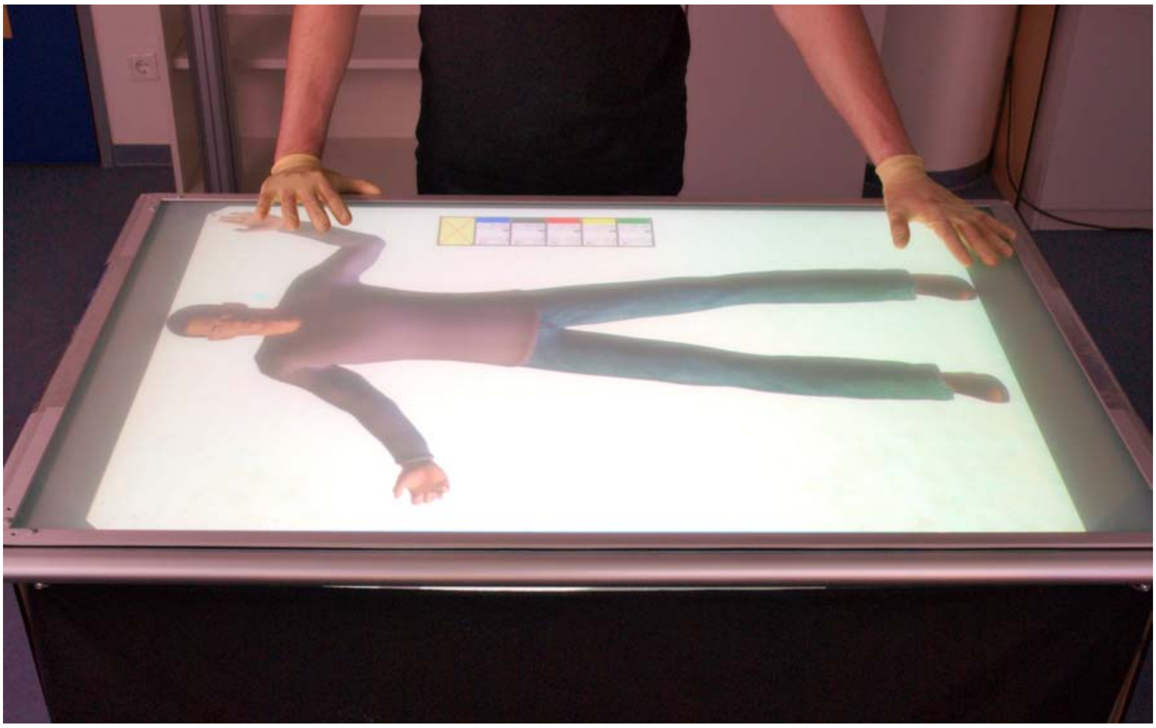

Figure 1: The virtual patient application on the multi-touch table top

4 Related work

The fact that touch is a very natural and intuitive way of interaction has been emphasized by Han during his work with multi-touch interfaces. He states that multi-touch interaction promises great improvements in usability, intuitiveness and efficiency due to the fact that gesture based interaction is feasible on multi-touch interfaces. Furthermore multi-touch interfaces facilitate multi-user interactions. When using multi-touch interfaces multiple users can simultaneously interact with the computer [Han06].

New ways of multi-user interaction are also researched by Shen et al. at the Mitsubishi Electric Research Laboratories. They focus on the collaboration aspects when working on horizontal interactive surfaces. They state that the interaction with the table top is quite similar to the interaction with paper when collaborating around-the-table. Furthermore they work out concepts how private and personal information can be included in the multi-user collaborative work at a shard table top interface [SER03]. In their further work they present the vision that the table has to 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].

Many research groups have already developed computer-based simulations for doctors and nurses working in emergency departments. Saunders et al. model emergency department operations by means of a computer simulation. Their simulation includes emergency department operations as well as the preceding triage processes. Their approach, however, does not include trainings for the involved doctors and nurses [SML89].

The existing patient simulation systems and computer-based trainings for doctors and nurses currently focus on the clinical environment. In Germany about 90 patient simulators are used for the further training of doctors. Patient simulations can give doctors the impression that they are working with real patients, provided that additionally to the patient also the clinical environment is simulated. Moreover some clinical procedures, such as Crisis Resource Management, can only be trained in simulations [MBV+99].

A patient simulation which can be used to train basic as well as advanced skills is proposed by Good. On the one hand the simulator can be used to teach basic skills, e.g. respiratory physiology and cardiovascular haemodynamics. On the other hand also advanced clinical skills, e.g. airway management or tension pneumothorax, can be trained at the simulator. Information about the skill level of the prospective users is of crucial importance for the training design. Medical students and practicing clinicians, for example, differ significantly in their previous knowledge [Goo03].

Kizakevich et al. proposed a computer based triage training which offers medical students the full range of medical devices. Instead of simulating the triage process as realistic as possible, their approach merely focuses on the training of medical students. Therefore in addition to the simulated patient info boxes and selection lists are shown which are not available in real disaster control exercises. Furthermore their solution does not deal with the question how to design intuitive interactions with the simulated patients. [KFHF06]

In conclusion simulation technology is playing an increasingly important role in skill training. Simulations, however, are not identical to "real life" events. 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 emphasize that simulation technology, which is now gaining wider acceptance in medicine, is already well established in other disciplines [IMH+99].

5 Designing the virtual patients

Although many computer-based patient simulations have been developed during the last years none of the existing systems is appropriate for triage training. In order to train the paramedics on the new mSTaRT-Algorithm a new system had to be designed.

On the one hand the interaction with the simulated patient has to be as close to reality as possible, on the other hand the change of patient patterns has to be performed very quickly. Manikins can not be used for triage training, since the change of the patient patterns takes too much time and interrupts the triage processes. Desktop computer-based simulations can be used with some limitations. Gutsch et al. presented a desktop computer-based simulation which is being used to familiarize the paramedics with the mSTaRT- algorithm [GHZ+06]. For the continuous training of the paramedics their approach is insufficient, because the proposed interaction with the simulated and animated patient is not close enough to reality.

Since touch is considered to be more natural and intuitive [Han06], we decided to use touch interaction for the advanced skill training. In real disaster environments the triage is not performed by single paramedics but by paramedical teams. Multi-user interactions with the patient happen quite often, therefore the hardware which fits best our requirements is a multi-touch screen. Furthermore multi-touch screens enable the use of two-hand gestures. This fact should not be underestimated, since some interactions require both hands as opposed to other interactions, which require only one hand. Therefore multi-touch screens - concerning the interactions - are mapping the handling of real patients more realistically.

6 Model and patterns of virtual patients

During the triage process the paramedics interact with the patients and check their vital functions. Paramedics, for instance, have to check whether the patient is able to walk. 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 the initial patient condition a complete patient model has to be designed.

6.1 Patient model

The interactive behavior of the virtual patient is controlled by a finite state machine. The most important state is the *neutral state* within which the virtual patient 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 within which the virtual patient exhibits appropriate reactions before returning to the neutral state. The generic model of Figure 2 provides several alternatives for "appropriate" behavior.

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 is performed by a time trigger (for the sake 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 as shown in Figure 3a.

Depending on the patient position (lying, standing or sitting) different transitions are

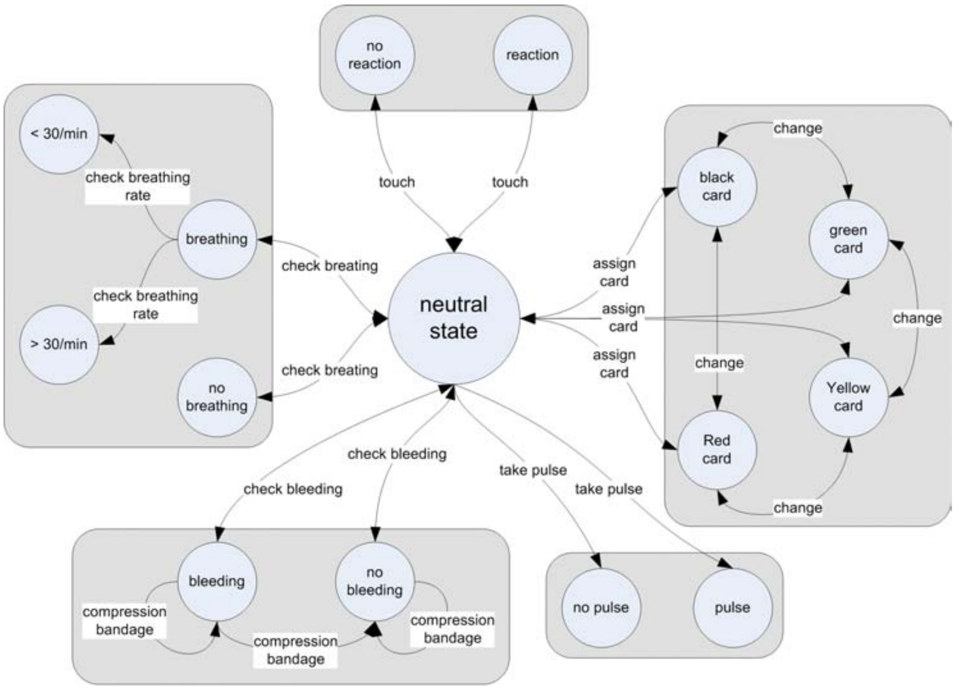

Figure 2: Patient states and transitions

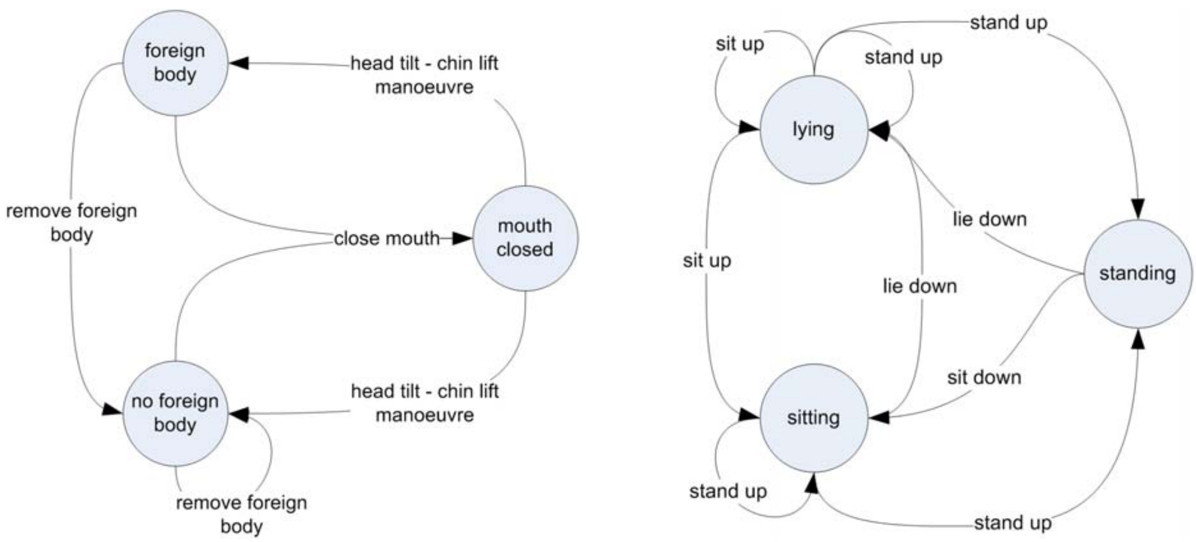

Figure 3: Patient model. (a) Removing foreign bodies. (b) Changing the patient position.

feasible. It is not possible, for instance, to perform a head tilt - chin lift maneuver with standing patients. The different patient positions and the transitions are shown in Figure 3b. 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 the finite state automaton is non-deterministic, as mentioned above.

6.2 Specific patient patterns

All possible interactions are contained in the general patient model, whereas the concrete patient information is contained in specific patient patterns. They contain the information whether a transition changes the state or not.

Our partners from the fire department Munich have already designed about 300 different patient models, which are in the process of being adapted to the computer-based simulation.

The combination of the patient model and the patient pattern leads to a deterministic finite automaton. Every time when the *touch* interaction is performed the new automaton either always changes to the state *reaction* or always changes to the state *no reaction*. Only the deterministic behavior of the simulated patients enable reproducible triage trainings.

Some transitions, however, still influence other transitions. As a consequence, the resulting deterministic finite state automaton 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 transition to the *breathing* state has been removed). After the removal of the foreign body, the *breathing* transition leads from the state *Z3* (which is equally visualized as the initial state *Z0*) to the *breathing* state. The paramedic, however, is not able to distinguish between state *Z3* and *Z0*, therefore from his point of view the system does not seem to be deterministic.

7 Implementation

In order to simulate the patients realistically, the virtual patients are based on human models that are exported from the Poser 6 software program (Curious Labs Inc., Santa Cruz, CA). At the moment each patient state corresponds with one patient view exported from Poser.

The different state transitions mentioned above have already been implemented on the multi-touch interface. In Figure 5a the paramedic is performing the head tilt - chin lift maneuver. He has to touch the patient's forehead and the patient's lower thorax at the same time. The red boxes illustrate the sensitive areas which belong to this gesture. During the training, however, these red boxes are not visible for the triaging paramedic.

After removing all foreign bodies, the paramedic checks the patient's breathing as shown in Figure 5b. In order to check the breathing he has to touch the patient's thorax. While the paramedic has not removed the foreign body no lifting of the thorax can be observed. These interactions are based on the state transitions mentioned in the previous chapter (Figure 4).

Provided that the patient is breathing, also the breathing rate can be checked. In real

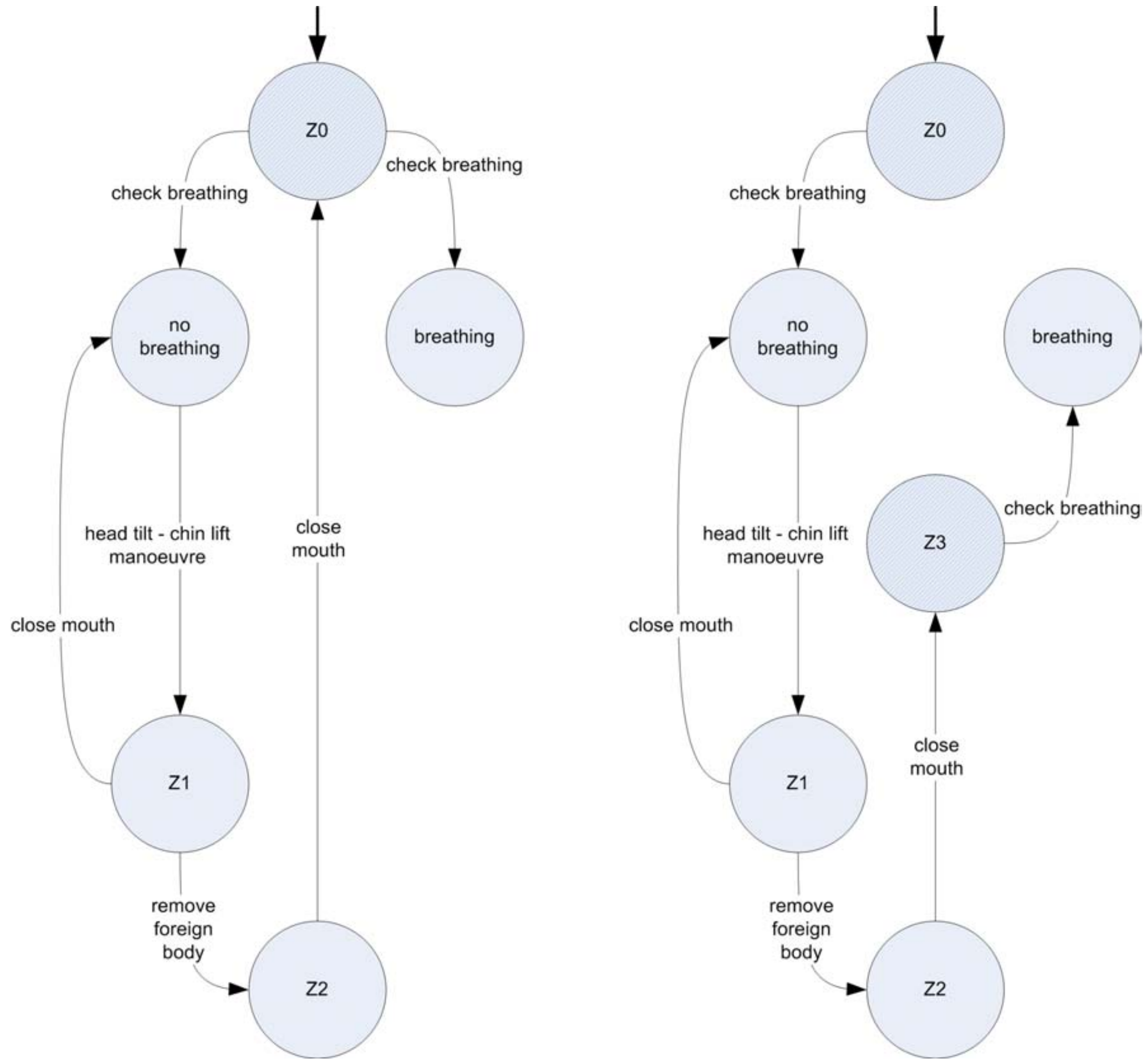

Figure 4: State automatons. (a) The general non-deterministic finite state automaton (b) The patient specific deterministic finite state automaton

Figure 5: Removing foreign bodies. (a) Performing the head tilt - chin lift maneuver and looking for foreign bodies. (b) Checking the patient's breathing.

situations the breathing rate has to be counted by the paramedics. In disaster control exercises, however, exercise actors tell the triaging paramedics their breathing rate after the paramedic has checked the breathing rate for about 10 seconds. This rather artificial setup of the training cannot be avoided due to the fact that it is quite difficult to simulate pathological breathing rates. In order to be comparable the computer-based simulation at the moment tells the triaging paramedic the breathing rate after checking the breathing for 10 seconds. In future versions of the simulation, however, the paramedic will have to count out the breathing rate on his own.

Figure 6a shows the paramedic helping up the lying patient by touching his shoulders. This interaction gesture is quite realistic, in reality the paramedic helps the patient up by grabbing him under his shoulders. Putting down the patient works in a similar way as shown in Figure 6b. The paramedic grabs under the patient's shoulders and helps him down.

Figure 6: Changing the patient position. (a) Propping up the patient. (b) Putting down the patient.

Although it is generally not reasonable to put standing patients down during the triage process, this interaction is nevertheless possible in the computer based simulation. Disaster control exercises give the paramedics the possibility to train basic and advanced pre-clinical skills, to make mistakes and to learn from them. Therefore also the computer based approach offers counterproductive interactions in order to give the paramedics the chance to make similar mistakes.

The allocation of the colored patient cards which indicate the severeness of the patient's injuries is reversible as well as modifiable as long as the triage process has not been finished. The associated interaction is shown in Figure 7. The triaging paramedic has to take the patient card and attach it to the patient by touching the desired patient card and the patient itself at the same time.

8 Conclusions and Future Work

Paramedics are required to perform different tasks in order to cope with disasters best. One of the major tasks which has to be performed by paramedics is the disaster triage. The triage

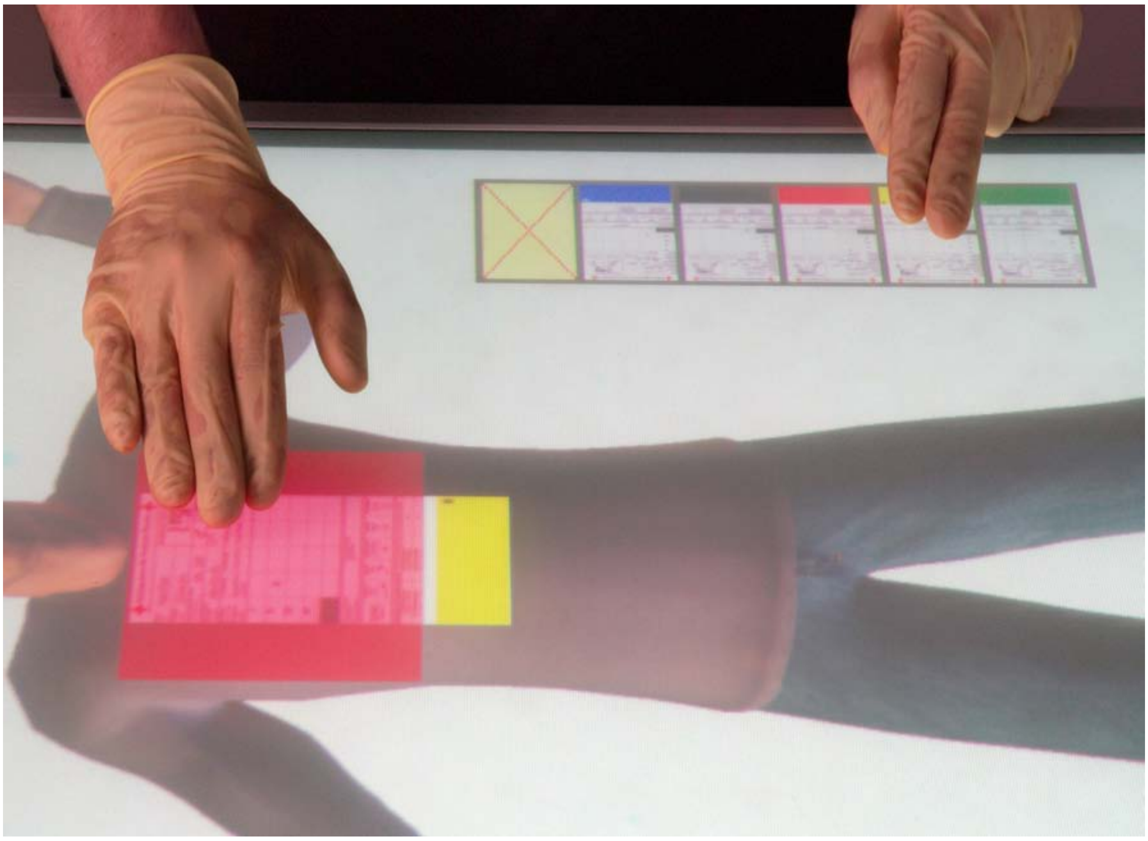

Figure 7: Applying the colored patient card.

process itself can be trained in small scale trainings. In addition to the basic triage training also advanced triage training has to be conducted. This advanced training - including not only the triage process itself but also the integration of the triage process in the whole disaster process - has to be trained in large scale disaster control exercises.

The proposed patient simulation puts the paramedics in the position to train required advanced skills in small scale trainings. Using a computer based approach additionally to the patient the concrete scenario can be simulated as well.

The fire department in Munich was very interested in the proposed computer based triage training. The first implementation has already been discussed with the paramedics and their feedback influenced the presented implementation. A major part of the further work is the evaluation of the current approach. In this evaluation the computer based triage training on the table top will be compared to a triage training with human actors. As already mentioned above, the simulator has to be as close to reality as possible. Therefore the evaluation has not to prove that quality and quantity of the triage processes performed on the simulator is higher than when using human actors. In fact the goal is to prove during the evaluation that quality and quantity are independent from the used training setting[2].

Another part of the further work is the enhancement of the system architecture. In the current implementation system control and patient handling is being performed on the table

[2]computer based training or training with human actors

top device. In order to be able to use the solution for training purposes, the system handling has to be isolated from the patient handling. The training settings, the patient patterns and the scenario has to be controlled by a supervisor who monitors the triaging paramedics. The more information the supervisor gets about the triage processes, the better he can adapt the training levels to the specific skill levels of the triaging paramedics.

The first steps in pointing out that computer based simulations are also feasible in preclinical environments are finished, the future work will therefore focus on improving the current design and implementation.

9 Acknowledgments

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