Virtual Agents based Simulation for Training Healthcare Workers in Hand Hygiene Procedures

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Abstract. The goal of our work is the design and implementation of a virtual agents based interactive simulation for teaching and training health care workers in the proper procedures for hand hygiene. The health care trainee in the simulation plays the role of a health care inspector in a virtual hospital that resembles a real hospital. The interactive training simulation features a virtual instructor who teaches the trainee the proper procedures of hand hygiene called the Five Moments of hand hygiene, recommended by the Centers of Disease Control and the World Health Organization, with demonstrations and instruction in a tutorial phase. The trainee then interactively practices identifying from observations, if virtual health care worker is following the appropriate procedure of hand hygiene when interacting with a virtual patient and the patient's environment from ten randomly generated virtual scenarios in a training phase. The trainee gets feedback on his evaluation of whether virtual health care workers in the simulated scenarios are performing their duties in accordance with the Five Moments of hand hygiene in an evaluation phase. We describe the design and development of the virtual hospital environment, simulated virtual instructor, health care worker and patient, and the interactive simulation components towards teaching and training health care best practices.

Keywords: Virtual Humans, Medical Virtual Reality, 3D Human-Computer Interaction.

1 Introduction

According to the Centers for Disease Control (CDC), healthcare-associated infections affect about two million patients in US hospitals each year [1]. Tragically, many of these hospital-acquired infections are preventable. Despite the fact that hand hygiene is one of the most important measures for preventing healthcare-associated infections [2, 3], hand-hygiene rates among healthcare workers remain unacceptably low [4].

Interventions which include feeding hand-hygiene rates back to healthcare workers can lead to improvements in hand hygiene practices [2], and improved rates can decrease healthcare-associated infections [2, 5, 3]. Thus, measuring hand hygiene is an important component of infection control programs, and one that is recommended by both the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) [2, 6]. Furthermore, the Joint Commission, the largest organization that inspects hospitals in the US, currently mandates that all hospitals monitor hand-hygiene compliance and during inspections asks hospitals not only what their rates are but also what they are doing to improve compliance. Currently, most observations are performed and recorded by human observers, and to date, this method is considered the "gold standard" for hand-hygiene measurement [7]. In short, the five moments or situations when health care workers should follow proper procedures of hand hygiene are defined as:

a. Before touching a patient.
b. Before clean/aseptic procedures.
c. After body fluid exposure/risk.
d. After touching a patient.
e. After touching the patient's surroundings.

To help educate healthcare workers about when to practice hand hygiene the WHO have defined a set of circumstances when hand-hygiene should be practiced using an alcohol rub or soap and water. These are referred to as the Five Moments. In prior research, interactive virtual humans have been used to teach and train verbal and non-verbal social behaviors in face-to-face conversation [8, 9, 10, 11, 12]. While there are short videos and posters to describe the Five Moments, to our knowledge there are no interactive virtual environments simulations with virtual humans for healthcare worker education that stress the importance of how observations should be done. We believe that training infection control professionals to appropriately observe and record hand hygiene is critical. We propose that these observation skills would more effectively be learned in an immersive, active, engaging environment. Indeed, most of the studies reviewed in the recent Agency for Healthcare Research and Quality report on the effectiveness of continuing medical education suggest that interactive techniques are more effective than non-interactive ones, and that multiple exposures are more effective than a single exposure in achieving and maintaining the objectives studied [13].

The design and development of interactive virtual environments with virtual humans for training health care workers in hospital best practices such as hand hygiene procedures, presents significant technical challenges that are distinct from those usually encountered when developing virtual humans for interpersonal face-to-face scenarios.

Here is a list of key contributions:

- A modular extensible component based training framework that includes virtual human modeling and animation, virtual environment creation, training logic, lip-synching and spatial audio, and user interface for interactive training and feedback for health care workers in clinical best practices.
- Our virtual agents based training simulation integrates a virtual instructor, health care worker, and patient in a pedagogical model consisting of tutorial/teaching phase, training phase, and evaluation/feedback phase.

- In order to train health care workers in hand hygiene procedures in an environment that is most similar to their working environment, we have integrated a pipeline in our simulation for the virtual recreation of a hospital environment from Computer Aided Design (CAD) models of the real hospital.

1.2 Related Work

Many virtual human agents in simulated real world environments have been developed for the purpose of training, pedagogy and education in a variety of applications. The strength of these systems towards training in socially collaborative tasks is in leveraging feedback and interaction with human users that virtual human interfaces can provide through verbal and non-verbal channels such as speech, gesture, and facial expressions. In this section we have highlighted a few relevant studies and applications.

Mel Slater and colleagues have found that theatrical actors and directors could effectively use virtual humans for rehearsals before a live performance [14]. Johnson et. al. have developed an immersive virtual patient framework for training medical students in patient interview training skills in simulated inter-personal conversation with virtual patients [9]. Raij et. al. using the virtual patient system examined perceived similarities and differences in experiencing an interpersonal scenario with a real and virtual patient [15]. They found that both levels of interactivity, richness and realism of the simulation, and interaction were important in facilitating the participants' ability to perform a training task with a virtual patient as effectively as with a real patient. Parsons et. al. are using virtual human patients towards training of novice mental health clinicians in conducting patient interviews using virtual patients that exhibit psychological disorders such as conduct disorder [16].

The Mission Rehearsal Exercise (MRE) system is an immersive virtual reality system with life-size virtual humans that was created to teach users leadership skills in task oriented situations [11]. The MRE uses fictional scenarios based on the real world situations towards training. ELECT BiLAT, developed at the ICT at USC, is a simulated virtual environment with virtual humans towards training army officers' culture-specific verbal and nonverbal behaviours in Middle Eastern culture [17]. Babu et. al. showed that immersive virtual humans in natural multimodal interaction can teach and train users social conversational nonverbal behaviours associated with south Indian culture [12]. Fear Not! Is an Interactive Virtual Environment (IVE) developed for education against bullying behaviours in schools [18]. The goal of this application was to offer children a safe environment where they can witness (from a third-person perspective) bullying situations in virtual 3D scenarios, and acts as an invisible friend or ally to the victimised character providing advice.

Our novel contribution is the design and development of an interactive virtual environment simulation with virtual humans towards teaching and training health care workers in clinical best practices towards hand hygiene. Trainees learn the Five Moments of hand hygiene procedure in a virtual hospital environment that resembles a real hospital, receive tutoring from a virtual instructor, and actively train and gain feedback by playing the role of a health inspector in several scenario based training

modules with virtual health care workers and patients. In the following sections we describe the design and implementation of our hand hygiene training simulation.

2 Interactive Training Scenario

The interactive training scenario is based on the notion of the trainee learning the hand hygiene protocols by playing the part of a health inspector that hospitals now employ in order to monitor compliance with the WHO/CDC recommended Five Moments of hand hygiene procedure. The trainee experiences three main phases in the training simulation. An initial title interface is used to guide the trainee through the simulation; the trainee also has the ability to revisit some of the modules if she wishes to do so. A simulation flow is shown in Figure 1 to highlight the programmatic sequence of events as part of the training simulation. In Table 1, we provide a description and screenshots of sample interactions of the trainee in the tutorial, interactive training, and feedback phases of the virtual agents based hand hygiene protocol training simulation.

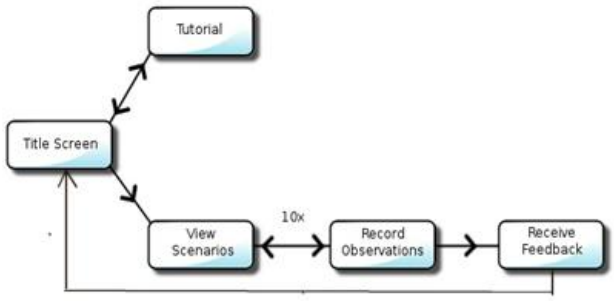
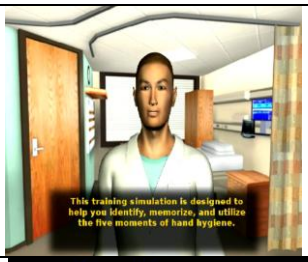
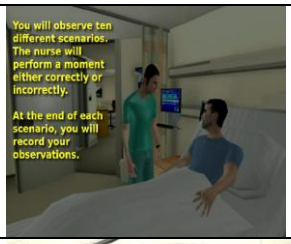
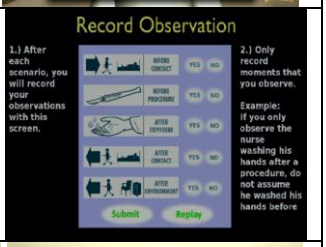


Fig 1. Shows a flow chart of the high level flow of interactive events in the hand hygiene training simulation.

Here are the three main phases of the training simulation:

1. A *tutorial phase* in which the trainee learns the Five Moments of hand hygiene one after another in succession from the virtual instructor "Dr. Evan". The virtual doctor informs the trainee that she will be tested in the Five Moments of hand hygiene procedure after the tutorial session. Dr. Evan then teaches the trainee the situations pertaining to each moment of hand hygiene with demonstrations, using speech, gestures and expressions.
2. An *interactive training phase* in which the trainee experiences ten randomly generated scenarios consisting of a virtual nurse "Simon" interacting with virtual patients in a hospital environment. The trainee has to evaluate if Simon follows the proper hand hygiene procedure after observing each scenario in which Simon interacts with virtual patients and/or their surroundings. The trainee records her observations via an evaluation interface.
3. A *feedback phase* in which the trainee receives a score of her performance in accurately identifying the cases when Simon in each of the randomly generated training scenario acted in accordance with the Five Moments of hand hygiene.

Table 1. Description and screenshots of the tutorial, interactive training, and feedback phases of the hand hygiene training simulation.

Description	***Screenshots***
1. Tutorial Phase: Dr. Evan welcomes the trainee to the hand hygiene training simulation.	 
Dr. Evan informs the trainee that he will be tested in the next session after the tutorial on Five Moments of hand hygiene, and must pay attention to his instructions and demonstrations.	 
Dr. Evan then teaches each condition of the Five Moments of hand hygiene by providing verbal and non-verbal instruction and demonstration. In this example, Dr. Evan teaches the first moment of hand hygiene, which is to wash your hands before contact with a patient. Clockwise the screen shots on the right show the instruction of the first moment of hand hygiene as provided by Dr. Evan, followed by a demonstration where Simon washes his hands using an alcohol based sanitizer, and then proceeds to appropriately meet the patient.	  
2. Training Phase: Dr. Evan presents ten randomly generated scenarios for the trainee to evaluate whether Simon is interacting with the patient in accordance with the proper protocols of hand hygiene or not. Screen shots of Simon interacting with the virtual patient and the evaluation interface where the trainee records his observations are shown on the right respectively.	 

3. Feedback Phase: Dr. Evan then provides feedback on how well the trainee performed in the interactive training session and presents the trainee with a score. The simulation then allows the trainee to revisit the tutorial, interactive training, and feedback sessions via the simulation interface.	

In the interactive training phase, the user is presented with ten scenarios in which the virtual nurse Simon interacts with the patient correctly or incorrectly according to the Five Moments of hand hygiene. These random scenarios are defined as follows. For moment one (before touching a patient), Simon either washes his hands or does not before shaking hands with the patient. In moments two (before clean/aseptic procedure) and three (after body fluid exposure), Simon gives the patient an injection and may or may not wash his hands before or afterwards. Simon checks the patient's pulse in the fourth moment (after touching a patient) and may or may not wash his hands afterwards. And, in the fifth moment (after touching patient surroundings) Simon types on the computer next to the patient to demonstrate touching the patient's surroundings and then may or may not wash his hands. The animations are played in random order every time the simulation scenarios are initiated.

3 Simulation Development Platform

All assets of the simulation were created in the Blender Open Source Framework [19], with the exception of the virtual humans which were modeled using Poser Pro [20]. The Blender game engine was chosen due to its integrated development environment for modeling, texturing, animation, simulation logic, and real-time animation engine characteristics. The built-in Python script engine was used to script behaviors for the virtual humans, simulation events, as well as the training interface.

Blender also provided the support for many advanced areas of virtual human modeling and animation such as armature-based and mesh-based animations, and integrating motion capture data for virtual humans [21]. On the graphical rendering side Blender provided features such as occlusion and view frustum culling, Python based networking, and collision detection. Poser Pro was used to render lip-synched animations with respect to the interactive speech behaviors of Dr. Evan.

4 Virtual Hospital Environment Creation

In order to create training simulations that can be evaluated in a future usability study by health care workers in the University of Iowa Hospital, we decided to virtually recreate the virtual training environment as close as possible to the real UI hospital.

This will enable the training experience to be as meaningful as possible for the trainees at the UI Hospital. Figure 2 shows a virtual replica of the real patient room at the University of Iowa hospital.

a) Virtual patient room in Blender b) Real patient room

Fig 2. Comparison of the the virtual (a) and real (b) patient rooms in the hand hygiene training simulation.

CAD files were imported into the Blender development environment to create accurate 3D models of the hospital. We then wrote Python scripts towards fine tuning the models such as correcting surface normals. After importing the models into the Blender environment a visual database of objects such as doors, beds, medical equipment were used to populate the scene according to the locations of objects provided in the CAD files.

A variety of graphics techniques were used to create a realistic simulation of the hospital environment including GLSL shading, normal maps, shadow/light maps, reflection maps, and ambient occlusion maps. Visibility culling and occlusion culling were used to optimize the complexity of the scene and to maintain real-time performance of the simulation.

5 Components of Dr. Evan, Simon and the Virtual Patient

In order to make our virtual humans believable we endeavored to model and animate realistic virtual characters in our training simulation. Poser Pro was used to create character geometry as well as the clothing and accessories such as hair. The resulting model was first decimated in order to enable real time rendering of the characters. We employed techniques such as normal mapping and retopology that mimics the high polygon model very closely to generate highly realistic appearance, which can be animated in real time. The final virtual humans used in the simulation were around 7,000 polygons each. Figure 3 shows the evolution of the virtual nurse Simon from the first iteration on the left at 76,500 polygons to the final model at 7,000 polygons on the right. The final outcome is optimized for real time rendering, and has a better appearance than the first and second stage virtual nurse models. Once the models were complete they were then imported into the Blender development environment for armature and facial rigging.

Fig 3. Stages in the development of the virtual nurse Simon from left (76,500 polygons) to the right (7,000 polygons).

6 Armature and Facial Rigging

In order to animate the virtual human, an advanced armature rig was created in the Blender environment. The armature was developed to supports inverse kinematics on the spine, arms, fingers, and legs. An advanced facial rig was also created to control facial expressions, and create speech behaviors. A combination of armature bone motion and shape morphing enabled us to create a wide variety of facial and body gestures. Gaze bones were used to animate pre-canned gaze behaviors. Figure 4 shows screenshots of Simon's armature and facial rigging process. The next step was skinning, where using the Blender "painting" feature we mapped the mesh to the armature. A weighted mapping procedure was used to account for the influence of a group of adjacent bones on the underlying mesh.

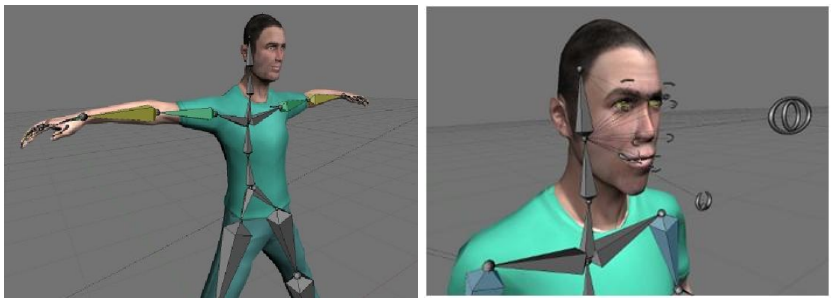


Fig 4. Shows screen shots of the body (left) and facial (right) armature rigging and skinning process of the virtual nurse Simon.

5 Animation and Scenario Modeling

Verbal and non-verbal actions of the agents were created using a series of keyframes in the Blender Action Editor (Figure 5). Keyframes were used to define every movement for each bone in the armature. The Blender Interpolation Graph Editor interpolates the animation between keyframes, so that the animator does not have to have to implement every keyframe. Interpolation can cause problems with animations

if keyframes are not position correctly. Every keyframe is composed of seven parameters pertaining to location, quaternion rotation, and scale of a single bone. The action editor is a collection of keyframes that defines an action i.e. administering an injection or washing hands. Our initial efforts to keyframe all the animations turned out to be tedious and time consuming. Therefore, we imported motion capture files from the Carnegie-Mellon Motion Database [22] pertaining to walking, hand washing, and patient intervention. Some time was dedicated towards cleaning and cropping of redundant motion capture frames prior to using them in the interactive training scenarios. However, the benefits of increased animation fidelity and believability resulting in the use of the motion capture sequences in the simulation made it worthwhile.

The non-linear editor encapsulates the actions into strips that are stacked and blended to create smooth animations. The non-linear editor can also utilize the stride bone technique in order to avoid foot slipping during walk cycles. The non-linear editor facilitated the compositing, blending, and interpolating multiple strips of animation. The non-linear editor supports armature-based and mesh-based animations. Facial expressions are controlled using a set of keyframed shape keys. A shape action contains an interpolation graph that controls the influence of the shape key. A combination of shape-key animations creates a wide variety of expressions, such as blinking, smiling and frowning. A simple python script was written in order to evoke the blink animation at random intervals within the simulation engine.

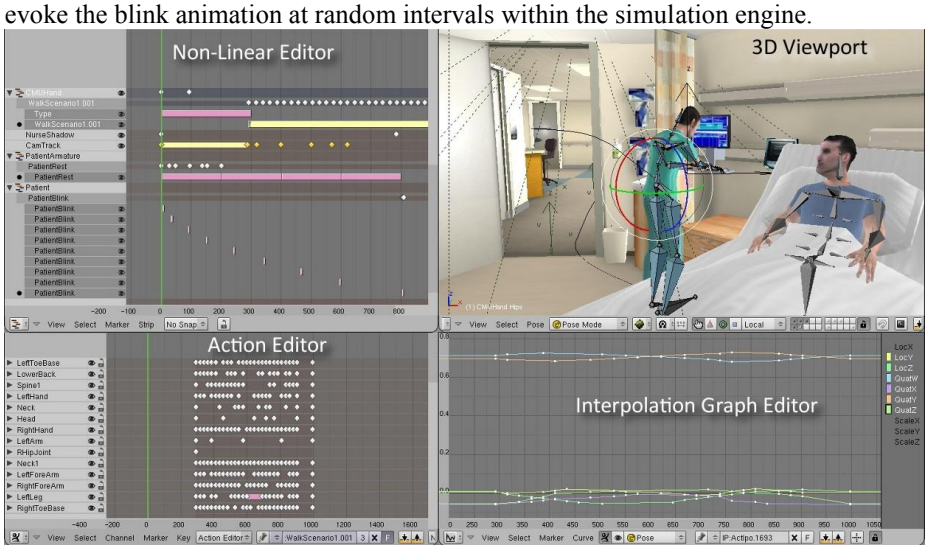


Fig 5. Shows a screenshot of our animation, modeling, and scenario control for a training situation as defined using the Blender virtual environments framework.

The agent's armature was parented to a path, and the path had a speed control interpolation graph associated with it, making it easy to control the speed of walking. The non-linear editor also enabled stride bone calculation. A stride bone was used to sync an agent's footsteps to the ground plane. A human's walking speed is almost never constant; there is usually a cyclical interval of slightly speeding up and slowing down. When an agent is moving along a path at a constant speed and the walk cycle action is set to repeat, their feet may appear to slip. In previous versions, we found

that this effect was very distracting for the trainee. The implementation of the stride bone takes into account the total distance from heel to heel covered by a single walk cycle and calculates the offset automatically. We then parent the agent to a Bezier curve to define path in the demonstration scenario, and set stride bone parameters to affix their footsteps on to the floor plane as they proceed along the path.

6 Summary and Future Work

Our novel contribution is a virtual agents based simulation for the teaching and training of health care best practices associated with hand hygiene. The simulation in particular is designed to interactively teach and train hospital workers in the Five Moments of hand hygiene procedure recommended by the CDC and WHO organizations. Our simulation features an interactive virtual doctor "Dr. Evan", a virtual nurse "Simon", and a virtual patient in training scenarios geared towards memorizing, observing, and utilizing the Five Moments of hand hygiene procedure. We have described the design and implementation of our interactive training simulation. Although, we chose the Blender virtual environments framework as the development platform for our simulation, we believe that the techniques used in the creation of our system are general to most current best existing simulation platforms.

Future work will focus on the evaluation of our hand hygiene simulation by health care workers at the University of Iowa Hospital in teaching and promoting awareness of the Five Moments of hand hygiene. The usability study will also include comparison of our current instruction, interactive training, and feedback system, vs. video based instruction, vs. traditional textual instruction on the effectiveness of learning health care best practices associated with sanitation and hand hygiene.

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