Towards Simulation Training for Nursing Surveillance

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ABSTRACT
Patient safety within hospitals is a growing concern in the medical community, since adverse events in hospitals often lead to prolonged stays due to complications, or patient death. Unfortunately, registered nurses fail to recognize the subtle changes and trends of deteriorating patients, possibly due to lack of repetitive and interactive continuing education opportunities for nursing surveillance. We developed the Rapid Response Training System (RRTS), which simulates a hospital, its patients, and their health records within a 3D virtual environment so that a nurse can practice observation and interpretation of patient symptoms towards better recognition of rapidly deteriorating patients. The RRTS was carefully designed for situated learning and broad usability and has the potential to increase patient safety by providing nurses with opportunities to improve surveillance skills.

Categories and Subject Descriptors
J.3 [**Computer Applications**]:Life and Medical Sciences—*health*. I.6.3 [**Computing Methodologies**]:Simulation and Modeling—*applications*. I.3.7[**Computer Graphics**]:Three-Dimensional Graphics and Realism—*Virtual reality*. K.3.1. [**Computers and Education]**:Computer Uses in Education.

General Terms
Design, Experimentation, Human Factors

Keywords
Nursing surveillance, virtual humans, virtual patients, rapid deterioration, simulation training

1. INTRODUCTION & MOTIVATION
Patient safety within hospitals is a growing concern in the medical community, since adverse events in hospitals often lead to prolonged stays or patient death. For example, from 2004 to 2006, 238,337 deaths of United States Medicare patients resulted from adverse events within a hospital[5]. Many of these patients demonstrated signs of deterioration in the hours prior to the adverse event, however, registered nurses (RNs) fail to recognize these subtle changes and trends [12].

Educating RNs on nursing surveillance, or obtaining knowledge and information through observation, investigation, and analysis of the data to identify threats, can potentially improve patient safety as nurses may be able to recognize rapid deterioration and medically intervene to prevent adverse events from occurring. In collaboration with St. Francis Hospital, we created the Rapid Response Training System (RRTS) to provide interactive and repeatable learning opportunities by simulating observation times during patient rounds in a nurse's twelve hour shift. The trainee is responsible for the surveillance of four simulated medical-surgical patients in a virtual hospital. The nurse's goal is to conduct surveillance as usual, but to recognize as quickly as possible which of the four patients is rapidly deteriorating. Simulation data can be interpreted to give nurses feedback so they can learn to better recognize the symptoms of rapid deterioration. The simulation can also be used as an analytical tool for medical experts to assess factors that trained nurses readily identify pertaining to patient deterioration.

2. RELATED WORK
To improve patient safety and prevent adverse events, many hospitals have in place a specialized, interdisciplinary team for rapid response to patients who display rapid deterioration [9]. The rapid response team follows specific procedures to prevent any further deterioration. St. Francis Hospital policy dictates that the rapid response team should be called when a patient displays a specific set of symptoms concerning heart rate, blood pressure, oxygen saturation, urine output, and behavioral changes [1]. Research outside of St. Francis Hospital confirms that many of these symptoms are indicators of patient deterioration [8].

Unfortunately, RNs often do not notice these symptoms [12] possibly due to inexperience [9] and lack of continuing education. Since medical knowledge doubles every 6-8 years, providing opportunities to continue education is crucial [10]. Current nursing surveillance education methods for practicing RNs are limited to text-based training, while the Agency for Healthcare Research and Quality reports that the most effective methods involve interactive techniques with multiple exposures [11]. Virtual reality training for healthcare professionals has the potential to increase training effectiveness by providing experiential, active, and situated learning that may increase learning transfer to real world tasks. Virtual reality can also simulate situations that are difficult or unsafe to replicate in real life and can offer individualized adaptation and feedback [11].

Many virtual reality simulations for healthcare training have already been successfully implemented. For example, Chodos et al. [6] implemented two simulations for healthcare training, one emphasizing procedural training, and another on communication skills. The procedural training application allowed emergency medical technician (EMT) students to practice procedures associated with assessing and stabilizing an accident victim. Students can interact with scenario objects in any order, supporting self-directed learning. The simulation for communication skills allows nursing students to interact with each other through Second Life to conduct patient assessment

conferences and to interview a standardized patient (an actor trained to simulate an actual patient) within the virtual environment. Vidani et al. [14] implemented a serious game to let nurses practice emergency medical response tasks. Nurses navigate through a 3D virtual environment representing a patient's home and choose tasks from a menu to perform the appropriate emergency procedures. The system plays animations to display each procedure. 92% of nurses agreed that the simulation could be useful for training, and 75% reported that they would use the application for training in the future. Nurses especially appreciated that the nurse character uniforms and medical equipment were modeled realistically. Gupta et al. [7] created a multi-agent interactive simulation to train healthcare workers in clinical hand hygiene procedures by allowing the trainee to act as an epidemiologist, recording virtual health professionals' correct and incorrect instances of hand hygiene. In a usability study, nurses rated the simulation as above average in engagement, realism, believability, interactivity, ease of use, and effectiveness.

Our primary objective in designing the initial prototype of the RRTS is to support the observation and data collection that is foundational to effective nursing surveillance. To support situated learning and increase usability, we modeled our system to closely match the everyday interactions of practicing RNs as described in interviews, videos, photographs, and demonstrations, and used actual medical data to ensure simulation fidelity.

3. SYSTEM DESIGN

Because our system is designed for a broad demographic of nurses who may not be familiar with computers, simulation, or any kind of 3D environment, we designed our system for natural interaction, carefully modeling the patient rooms, electronic health record (EHR) system, and interaction techniques after actual nurse experience. Working from videos of demonstrated nursing techniques, photographs of hospitals, equipment, and hospital personnel, screenshots of existing hospital software, and actual patient data extracted from medical records, we created the RRTS to closely simulate the working environment of nurses. The use of actual medical data when possible also ensures that our simulation is medically accurate and can be more easily validated.

The RRTS is designed to run on a dual-monitor computer. On the left monitor, the displayed virtual environment simulates the hospital wing and enables the nurse to travel to patient rooms, use medical equipment, and ask the patient questions to evaluate his or her condition. The right monitor displays an EHR for the patient, already filled with the patient's relevant medical history. The nurse may record his or her observations in the EHR as well.

Our application can simulate a full twelve hour shift, although it is designed to end as soon as the nurse identifies the rapidly deteriorating patient. Since nurse rounds occur approximately every three hours, our simulation allows the nurse to evaluate each patient in four discrete time steps. The simulation begins at 7:00 AM simulation time, and the right screen displays a first-person perspective of a nurse at a desk in the hospital hallway. The nurse can select a patient's door to enter into the patient room or to interact with the patient's medical record. The nurse can also select a button to advance to the next time step, which will add data to the patient's EHR as would occur between nurse rounds as nurse aides check patient vital signs, and will possibly change the patient's condition as it would change over a three hour time period. The nurse continues to advance through each of the four time steps, or until he or she recognizes which patient is exhibiting signs of rapid deterioration.

Every nurse-system interaction is time stamped and recorded. Each selection is recorded by its screen coordinates and associated action. All data entered in the EHR is recorded into a database.

3.1 Patient Model

Our patients are modeled directly after actual patients who have gone through rapid deterioration at St. Francis Hospital. We have the actual medical records for these patients, which include information such as demographics, medical history, medication record, and vital signs during their stay at the hospital.

We have changed all patient names and removed any other personal identifying information to ensure patient privacy and HIPAA compliance, but have modeled our virtual patients to closely resemble the demographic and medical condition of the original patient. Additionally, in the patient record, there are notes about the social characteristics and general demeanor of each patient. For each of the questions that a nurse may ask the virtual patient during the simulation, we have worked closely with experienced nurses to create verbal and nonverbal responses that are characteristic of a patient with a similar demographic, demeanor, and medical condition. The virtual patient's quantitative data for vital signs is drawn from the medical charts.

Because each patient is an individual with infinite possible data points that could be gathered, we could not simulate every possible nurse-patient interaction. We chose to focus our simulation on demonstrating key symptoms that would indicate that a rapid response team should be called to prevent further deterioration according to St. Francis Rapid Response policy [1]. Additionally, since our patient records can only show what happened to the patient in the hospital, to preserve medical validity we only allow the nurse to observe the patient and not to intervene to alter their condition and its outcome.

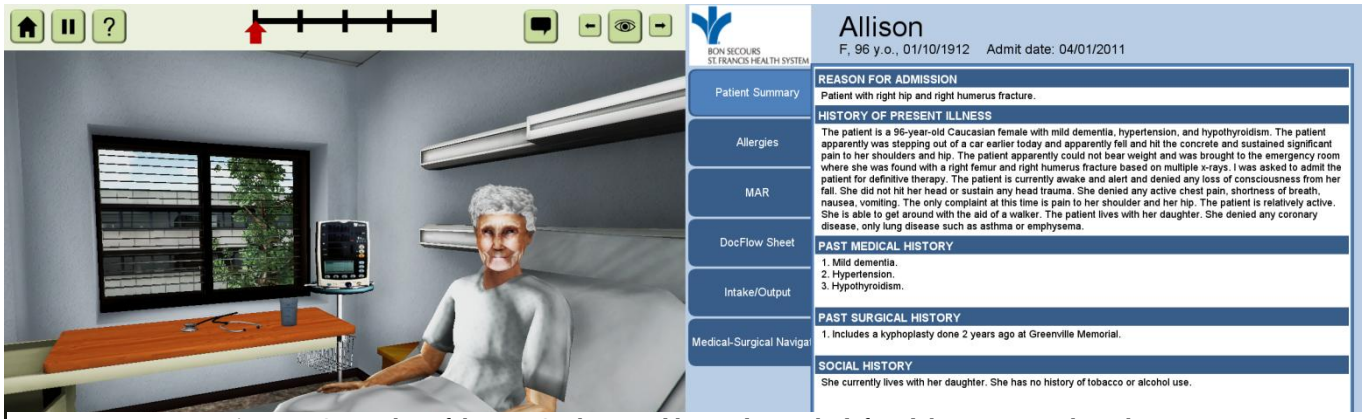

Figure 1. Screenshot of the RRTS. The virtual hospital is on the left and the EHR is on the right.

3.2 Electronic Health Record

The user interface for the patient's electronic health record (EHR) is closely modeled after the existing system at St. Francis Hospital to reduce the time and frustration associated with learning a new records. The patient's name and basic information is displayed at the top of the screen. On the left side of the screen, tabs enable nurses to navigate through the patient's records. Since the nurse is not permitted to perform any kind of procedure or intervention on the patient, the majority of the record is read-only, including the patient's medical history, demographic information, and medication administration record. However, in each time step, the nurse is permitted to record the observations that we enable while in the patient room. Data is input using a variety of methods including checkboxes, radio buttons, and numerical input, according to how the data would be recorded in the existing system. Although most design decisions centered on replicating the existing EHR to increase learnability, we also improved upon the existing design in our application, using larger fonts, better spacing, and simplified data display to increase usability [13].

3.3 Virtual Hospital

Since nurses are familiar with a hospital setting and the tasks of patient care, our virtual environment replicated the hospital as realistically as possible. Instruments, patients, and hospital staff were modeled after photographs and videos of actual equipment and people. To replicate the many distractions a nurse may encounter when in a patient room, our system also simulates various events that may be occurring in the hospital. Virtual characters simulating doctors and nurses can be seen walking in the hallways. Family members and friends of the patients may be present in the room. While in the patient room, nurses hear the ambient noise of conversation and footsteps in the hospital hallways and may hear or see a patient's television.

After we modeled the virtual hospital, we faced the challenge of designing interaction techniques for the virtual environment. Personal interaction with patients and use of medical equipment are hands-on, immersive interactions which can be difficult to enable within a virtual environment, especially for audiences who may not be familiar with established 3D gameplay techniques. To support natural interaction, and to help the trainee to conceptually separate the dialogue-based interaction of the EHR from the manipulating and exploring interaction required in the virtual hospital, we designed the virtual hospital to be usable for touch screen interaction [13]. We adhered to design guidelines for touch applications by limiting user choices, providing feedback during and after interactions, making interactions selection-based, and making targets large enough to accurately target using a finger[4]. Our design is also compatible with traditional mouse interaction—selection is accomplished by clicking instead of touching, and targets large enough for selection using a finger are also large enough for mouse selection.

The virtual hospital screen is divided into two sections. The navigation bar at the top of the screen enables interaction that cannot be easily represented by interacting with objects within the virtual environment, while all other interactions are represented in the remainder of the screen that contains the virtual hospital.

3.3.1 Navigation Bar

Each button on the navigation bar employs a familiar web browser or VCR style icon in hopes of increasing usability through standardization [13]. The nurse may use the buttons in the navigation bar to pause the simulation, acquire help, view simulation time along a timeline, and control the camera.

Because nurses may not be familiar with typical video game style camera positioning, such as using arrow keys to change position and mouse to choose viewing orientation, we implemented a simple system for controlling camera perspective. The nurse can use right and left arrows in the navigation bar to rotate the camera orientation clockwise or counterclockwise, allowing him or her to see other portions of the environment. If the nurse would like to "zoom in" to any area of the room, he or she may select the eye button in the navigation bar, then touch the area he or she would like to look at more closely. The camera then automatically moves to bring that area into full screen view. The nurse may select the eye button again to return to the original viewing position.

Navigation from a patient's room to the nursing desk is also enabled by a button. While in the patient's room, a "Home" icon allows the nurse to return to the nursing desk. Also, navigation through time is controlled by a button. While at the nursing desk, the nurse may advance to the next simulation time step.

Since it may feel invasive for a nurse to touch or click on a patient for interaction, and questions that nurses ask are fairly standardized, the nurse may also interact directly with the patient by using a menu that drops down from a "quote bubble" button. The menu lists questions that nurses typically ask patients to gauge their condition, as reported to us through our interviews with nurses and observations of their patient care procedures. The questions are separated into categories that provide submenus in order to best manage screen space and to limit user choices in keeping with usability guidelines [4, 13]. When the user selects a response, the patient may respond verbally and/or nonverbally, and the camera may move to give the nurse the perspective needed to answer his or her question. Example questions and responses are shown in Table 1. Patients also may display behavioral symptoms such as labored breathing, restlessness, or unresponsiveness. Nurses can synthesize verbal interaction and observation of nonverbal behavior to determine the patient's mental orientation level and the general condition of a patient.

Table 1. Example questions and responses.

Category	Question	Response
General	How are you feeling today?	*Patient smiles.* Oh, I am beginning to feel much better! I'm still feeling weak though.
Orientation	Who is the president?	President Obama.
Systems	Are you having any chest pain today?	*Patient shakes her head and places her hand on her chest.* No chest pain. I feel like my heart is beating a little faster than normal, though.
Condition-specific	Can I take a look at your hip?	*Patient nods and camera automatically zooms in to the hip injury site.*

3.3.2 Virtual Environment

In the virtual environment, when the nurse enters a patient's room, the patient is displayed in his or her hospital room with several medical instruments in his or her surroundings. Since it would be time-consuming to model every instrument a nurse could use, we only modeled instruments most likely to support nursing surveillance with respect to detecting rapid deterioration.

Several instruments offer quantitative measures of a patient's condition using either a digital display or measurement markings on a gauge. Using a "nurse-on-a-stick", the nurse can measure the patient's heart rate, oxygen saturation, temperature, and blood

pressure by choosing an option and reading digital output from the instrument's screen. The nurse may monitor IV rate and intake by reading the digital display of the IV meter.

Other patient data may be gathered through the nurse interpretation of instrument-patient interaction. Oral intake is measured by observing a cup with measurement markings, while urine output is measured by observing a urine hat for female patients or a Foley bag for male patients. With the stethoscope, the nurse may listen to the chest, back, and stomach of the patient.

To provide feedback, accommodate for accidental selection, and allow for multiple functions for one instrument, we employ three-step interaction for each instrument. When the nurse clicks or touches an instrument, the instrument is highlighted with a glowing halo and a tooltip appears, instructing the nurse to touch or click again to use the instrument. If the nurse touches another location on the screen, the halo and tooltip disappear. If the nurse touches the item again, a menu appears listing each function of the instrument as well as a "Cancel" button. If the user selects the cancel button or touches or clicks off of the menu, the menu and the item's halo disappears. If the user selects an action from the menu, the item performs the appropriate action (for example, the patient's temperature is digitally displayed on the nurse on a stick, or the stethoscope moves to the chest and heartbeat sounds are played). To reduce manual camera manipulation, the camera automatically zooms in so that the nurse can read its displayed data easily. A "Back" button is provided on screen so the nurse can return to the original viewpoint.

3.4 Implementation Details

The EHR and patient room screens are implemented as a single project in Unity3D [3]. The patient rooms are implemented through the standard game-play capabilities of Unity, while the top navigation bar for the patient rooms and the entire EHR are implemented through Unity's GUI capabilities. We made custom GUI controls to enable the necessary selection techniques for the EHR and wrote custom scripting to automatically resize the application to cover both monitors in full screen.

Our virtual characters, hospital rooms, and instruments were modeled and rigged in Blender [2]. Patient data is stored in a MySQL database and accessed using scripting. Interaction data is written to a text file and also recorded in a MySQL database.

4. FUTURE WORK

We have planned a user study to gather usability feedback from nurses as well as to test our hypothesis that using a touch screen for the patient room along with a standard monitor with keyboard and mouse for the EHR will provide for more natural interaction, increasing usability. After we modify our system to take into account nurse feedback and to maximize usability, we plan to extend our system to give nurses feedback on how to improve their surveillance skills. Potential improvements in observation skills can be determined by analyzing which instruments and interactions nurses used or routinely neglected to use, while improvements in data synthesis and analysis may be determined by pinpointing inaccurate interpretations of qualitative data such as heart and respiratory rates or patient nonverbal behaviors. Additionally, analysis can yield feedback for other problems such as recording errors, and can also provide positive feedback. As nurses use our simulation multiple times gathering feedback, we can measure their progress to track improvement and compare their performance to those learning using traditional methods.

We would also like to apply intelligent tutoring system techniques so that our simulation can adjust to a nurse's capabilities by increasing difficulty over time. Another possibility is to implement a patient model allowing the nurse to perform interventions such as giving medication, and to change the patient's symptoms with the expected result of the intervention.

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