Virtual Patient Model for Multi-Person Virtual Medical Environments

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Abstract
We describe the architecture of a virtual patient model, the Virtual ED Patient, for scenarios in emergency medicine. The model is rule-based, and uses four vital signs as a representation of its state. The model is used in a multi-person learning environment based on online gaming technology. The efficacy of the model and the Virtual ED learning environment is evaluated in a study where advanced medical students and first year residents manage six trauma cases. Pre and post-test performance results show significant learning, with results comparable to those obtained in human manikin simulators. Some future directions for development of the model are also presented.

Introduction

Numerous patient simulations have been developed, with underlying medical models. Most of these simulations have been a snapshot of the patient's condition (patient state) at the time of encounter with the physician (learner). In these cases, the simulation represents a single medical state, often in considerable detail, and with relevant graphics, audio and visual media displaying the patient's medical condition[1]. Some simulations support the evolution of the patient's state, both with and without medical intervention. Figure 1 is a generalized representation of such Virtual Patient models.

The medical model is represented by the "Physiologic Process" block together with the evolution of the physiologic process, as represented by the feedback loop "Time Step". The "Intervention interface" represents the ability to change the physiologic state through clinical, surgical or pharmacologic intervention. The "Patient state" is represented by the current values of the "Physiologic process" variables. The "Patient State" is presented to the learner in many ways. The "Query interface" is the method through which the learner can obtain additional information about or from the patient. Some of this information may be available by default, such as the initial appearance of the patient, or the report from the referring physician or the ambulance personnel. In the simplest form, the presentation can be in text and numbers. Alternatively, rich multimedia may be used. The choice of presentation format is usually based on the learning goal. Some of the "Patient state" variables may not be observable, or may require sophisticated and time consuming tests.

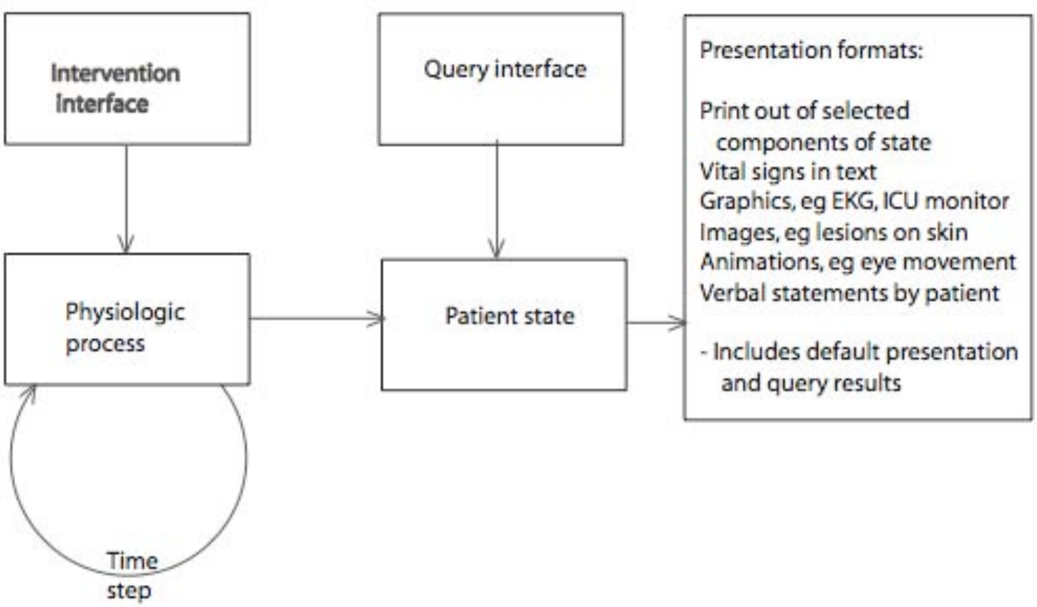

Figure 1. Block Diagram of Virtual Patient medical model and patient presentation

Method

We have developed a Virtual ED (Emergency Department) with trauma patients whose medical condition evolve over time. Each patient presents with a brief medical history as reported by the ambulance team (fig. 2). The underlying medical model determines initial and evolving medical state.

Patient History
Bicycle rider, 24 year old, struck and run-over by an automobile, causing blunt trauma to abdomen and de-gloving injury of hand. He complains of abdominal pain and is brought to the ED with a bleeding, lacerated hand, and in moderate shock.

Figure 2. Initial patient report

Four important vital signs were selected for modeling the physiologic dynamics of trauma cases – blood pressure, heart rate, respiratory rate and oxygenation. Each is assumed to remain constant in a normal person. Under trauma, any or all of them may be programmed to change because of a physiologic insult. For example, if the trauma case includes possible internal injury, the corresponding loss of blood is accompanied by a steadily decreasing blood pressure and increasing heart rate. In our model, this is simulated as a linear change over time in these two variables. A different type of trauma, such as a blocked airway, may cause a more sudden change in a variable such as respiratory rate.

State variable (vital signs)	**Dynamics of state variable**
Heart Rate	Constant, changing linearly because of specified trauma condition, or changing discretely because of intervention
Respiratory Rate	same
Blood Pressure	same
pO2	same

Table 1. "Patient state" variables in the Virtual ED Patient model

The medical model is "rule-based", and differs significantly from the highly detailed mathematical models that underlie the pharmaco-physiologic medical models appropriate for anesthesia simulation[2]. (See code fragments in Appendix for our rule-based method.). The four vital signs represent the "observable" state of the model. Other unobservable states, such as blood volume, impact parameters such as rate of change of blood pressure, but their value and change are not computed in our basic medical model. The vital signs are not linked computationally such as through a simulation of the cardiovascular or respiratory system.

In this model, we can specify both gradual changes in physiologic variables as well as a number of discrete important "states", with the patient moving from state to state based on the trauma and on the actions taken by the learner.

The "Intervention interface" and "Query interface" include a rich repertoire of actions. Each action is initiated by clicking on a menu button. Each action is used to collect information, to change the Patient state, or both.

Intervention (and Query)	**Outcome**
Trendelenberg	tilts the gurney by swapping models **(change BP)**
Flatten Gurney	flatten the gurney by swapping models **(change BP)**
Clear Airway	reports back findings **(clear if blocked)**
Administer Glucose	reports back findings **(change vitals)**
Give Blood	prompts for more information **(change vitals)**
Administer O2	reports results **(change vitals)**
Chest Needle	reports results **(change vitals)**
Insert IV	prompts for more info **(change vitals)**
Hyperventilate	reports results **(change vitals)**
Endotracheal tube	reports results **(change vitals)**
Chest tube	reports results **(change vitals)**

Table 2. "Interventions" available in the Virtual ED Patient model

Query only	**Outcome**
Get Patient Report	presents report to all users
Check Femoral Pulse	reports back current pulse
Check Radial Pulse	reports back current pulse
Check Pedal Pulse	reports back current pulse
Check Precordial Pulse	reports back current pulse
Palpate Head and Neck	reports back findings
Palpate Upper Extremities	reports back findings
Palpate Thorax	reports back findings
Palpate Lower Extremities	reports back findings
Palpate Back	reports back findings
Send for X Rays	prompts for more information
Rectal Exam	reports back findings
Examine Pupils	reports back findings

Attach Pulse Oximeter	displays pO2 in vital signs panel
Attach Chest Leads	displays HR, RR in vital signs panel
Check Airway	reports back findings
Auscultate Chest	
Take Blood Pressure	displays BP in vital signs panel
Auscultate Abdomen	reports back findings
Palpate Abdomen	
Ultrasound	

Table 3. “Queries” available in the Virtual ED Patient model. “Reports back findings” gives a text message.

In the Virtual ED, the execution of each intervention is represented as an animation, with the corresponding avatar making the motions for that intervention. Some interventions change the state of the vital signs, and their corresponding display. Certain Patient State variables change if the corresponding interventions have happened. This information is stored in flags (yes/no variables).

Patient state flags	**Flag state**
caseNumber	store the case number
sessionStart	flag to indicate whether task has been done
insertIV	flag to indicate whether task has been done
takeBP	flag to indicate whether task has been done
chestNeedleDone	flag to indicate whether task has been done
IVhand (R/L)	flag indicating whether item is present
IVcubital (R/L)	flag indicating whether item is present
IVjugular (R/L)	flag indicating whether item is present
chestTubeFlag	flag indicating whether item is present
airwayFlag	flag indicating whether item is present
endoFlag	flag indicating whether item is present

Table 4. “Patient state” flags in the Virtual ED Patient model

Advantages and disadvantages of Virtual ED Patient model

A key advantage of this model is that it is easy for medical subject matter experts (physicians) to understand how to design patient cases. For any trauma victim, they can describe how the vital signs will be altered, and the other symptoms that should be displayed. The rules themselves are easily programmed in any language (we used Javascript). The limitation has been our ability to display animations of the many complex interventions. We have chosen to animate a few, and have simply implemented others as text responses to menu selections.

The disadvantage is that as the number of correlated physiologic variables increases, the programming effort, and the possibility of error, increases. Therefore, at present, this method is best suited to implementation of simple physiologic situations.

Results

Twelve senior medical students and four first year EM residents trialed the Virtual ED. All reviewed basic trauma management and EMCRM team leadership skills prior to initial orientation to the simulation system. Pairs of trainees were teamed with two standardized team players—an ED physician and nurse—for a half-day training session. The four-member teams worked together over the internet, in real time with voice communication, to manage a virtual patient exhibiting signs and symptoms of a traumatic injury. Users selected the appropriate avatar actions from the menu to virtually assess and manage the cases. Guided by the Emergency Medicine Crisis Resource Management (EMCRM) curriculum, the team worked through cases, applying basic principles of trauma management and effective teamwork.

Each team managed six cases, including a pre and post assessment case, with trainees alternating the leadership role. An ED faculty member led the debriefing sessions after each training case.

The ED faculty member and standardized team members were trained on using the EMCRM objective, structured, rating scale. They observed and rated each trainee’s team performance on the pre and post assessment cases. Trainees also completed a questionnaire to provide feedback on their perceptions of the learning experience.

A pretest-posttest comparison of mean scores was computed and the difference was found to be statistically significant (Wilcoxon Signed Ranks test, $Z=-3.52$, $p=0.00$) showing that the trainees’ performance scores improved between the pretest and the posttest cases. All trainees reported feeling this type of simulation would be either “useful” (19%) or “very useful” (81%) in learning to initially assess and manage trauma patients.

The performance of this group was compared with that of a similar group who managed the same six cases in a human manikin simulator environment. The two groups showed similar improvement, indicating the capability of the Virtual ED as a valid learning environment[3] (fig. 3).

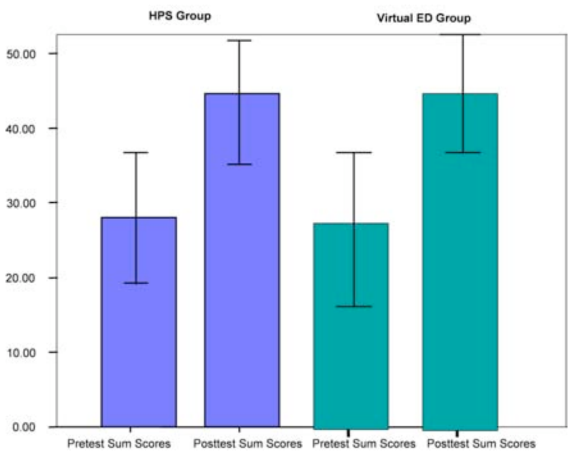

Figure 3. Mean scores are shown for students in the Human Patient Simulator group (first two bars) and in the Virtual ED group (second two bars). Significant and comparable improvement is displayed by both groups between pre-test and post-test cases.

Conclusion

We are currently extending the patient model to support training scenarios for two types of mass casualty disaster, as they impact the hospital's ED:

– Sarin aerosol attack – liquid dispersion of sarin gas in a subway train

– "Dirty Bomb" attack – explosion of a bomb with radiological materials in a car at the front of a building.

Our initial analysis indicates that the Virtual ED Patient model may be extendable while retaining its rule-based approach. The training scenarios will include the medical events in Table 5.

Medical Event	Parameters
Trauma	
Heart Attack	Type, Location, Severity
Stroke	
Seizure	
Anxiety Attack	Type, Severity
Exposure to Toxins	Type, Concentration, Duration

Table 5. Medical events.

The scenarios will require additional presentation of injury or pathology, a few of which are presented in table 6. We indicate how we plan to deal with the additional computational and visualization needs. Additional diagnostic procedures are planned (table 7) with some related treatments in table 8.

References

1. Lyon HC Jr, Healy JC, Bell JR, O'Donnell JF, Shultz EK, Moore-West M, Wigton RS, Hirai F, Beck JR. PlanAlyzer, an interactive computer-assisted program to teach clinical problem solving in diagnosing anemia and coronary artery disease. Acad Med. 1992, 67:821-8.
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3. Youngblood P, Srivastava S, Harter P, Dev P, Wallen C-J, Tsai L, Heinrichs WL. 2005. Validation of a web-based VR simulation for training trauma teams. MMVR'2005

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Appendix: Sample Code

```
//This part continually loops to update the vital signs

loadAll = new Object();
loadAll.timestep = function(now)
{
      curHR =
baseHR+incrHR+Math.round(HRRate*(now-
startT))+Math.round(3*Math.random());
      if (curHR < 115) curHR = 115;
      if (curHR > 145) curHR = 145;……..
      curBPs =
baseBPs+incrBPs+Math.round(BPsRate*(now-
startT))+Math.round(2*Math.random());
      curBPd =
baseBPd+incrBPd+Math.round(BPdRate*(now-
startT))+Math.round(2*Math.random());
      if (curBPs < 50) curBPs = 50;
      if (curBPs > 85) curBPs = 85;
      if (curBPd < 30) curBPd = 30;
      if (curBPd > 55) curBPd = 55;
}

//This shows the message presented when pushing the
'Palpate Head' button
      PalpateHeadB.onClick = function()
      {
        if (atRightArm(player.position) ||
atLeftArm(player.position) || atHead(player.position)) {
              sendJS("alert(\"There is a wound on the
forehead.\");");
        }
        else {
              sendJS("alert(\"You are not in the correct
location to palpate the head and neck region.\");");
        }
      }
```

Condition	Process	Description
Bleeding	Modify Texture	If this is dynamic, when does it start, is it steady, or does it change suddenly
Wounded Limb or Torso	Animation	This is a patient state variable (flag) but is not dynamic
Coughing	Animation	Does coughing change during the simulation. Does it respond to changes in physiologic condition. For example, death.
Heavy or Shallow Breathing	Animation	Does the depth of breathing correlate with the respiration rate, which is already modeled.
Seizures	Animation	This could be an animation that is triggered randomly. Alternatively, a new physiologic variable could be created that triggers seizures.
Unconsciousness	Animation	Same as above.

Table 6. Selected methods of presenting or triggering Medical Conditions

Examination Name	Instrument (visuals)	Output
Measure heart rate	Stethoscope	Heart rate variable exists. Can trigger text, graph, or audio if available.
Measure papillary constriction, tears		Our variable – "Examine Pupils", generates text output.. Could use image or animation.
Examine airway	Tongue blade	Our variable – "Check Airway", generates text output.
Measure blood pressure	Sphygmomanometer	Variable exists. Reports text.
Record ECG	ECG Monitor	Heart rate variable could trigger an ECG tracing (image). Complexities in ECG may need additional variables.
Imaging of injured regions	X-Ray	New variable. Its values are the various possible states of the injured regions. (text)
Glasgow Coma Scale (GCS)		New variable. Is this expected to change during the course of the simulation? Its values could be the various possible consciousness states. (text)

Table 7. Selected diagnostic procedures

Treatment	Instruments (need visuals)	Response of model
Tongue Blade, Oral Airway	Place appliance, latex gloves	Change value of airway state
Tourniquet	Latex rubber strip, latex gloves	Change flag to say tourniquet is applied
Bandages	Bandages, tape, towels, latex gloves	May impact blood loss. Other effect?
Fluid Therapy	IV bag and tubing, needles, latex gloves	Impact blood volume
Administer Oxygen (O_2)	Face mask, tube, canister	Impact oxygenation
Insert Chest Tube	Skin prep.,chest-tube, bandages, latex gloves	Variable for pneumothorax. Exists in SUMMIT model
Administer Medications	Prep., needle/syringe, IV ; e.g., 2-PAM (Pralidoxime), atropine, 50% dextrose, morphine, analgesics, latex gloves	Impacts vital signs. May need additional variables.
Transfuse Blood	Prep., needle/syringe, IV ; blood pack cells, latex gloves	Impacts blood volume.

Table 8. Selected treatment procedure