Trust in Emergency Evacuation Robots

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Abstract—**Would you trust a robot to lead you to safety in an emergency? What design would best attract your attention in a smoke-filled environment? How should the robot behave to best increase your trust? To answer these questions, we have created a three dimensional environment to simulate an emergency and determine to what degree an individual will follow a robot to a variety of exits. Survey feedback and quantitative scenario results were gathered on two different robot designs. Fifteen volunteers completed a total of seven scenarios each: one without a robot and one with each robot pointing to each of three exits in the environment. Robots were followed by each volunteer in at least two scenarios. One-third of all volunteers followed the robot in each robot-guided scenario.**

Index Terms—**Emergency Evacuation, Human-Robot Interaction, Emergency Simulation**

I. Introduction

Emergency situations can be confusing and chaotic. It can be difficult to see exit signs or understand instructions from other people. Emergency evacuation robots offer many advantages over traditional methods of notification and guidance. Typically, the only notification that people receive about an emergency is a buzzing alarm. The only guidance they receive comes from stationary signs and their own recollection. Emergency personnel can assist, but they need time to arrive at the site and take a great risk by entering a building during an emergency. Robots can be stored in the buildings and become active as soon as an evacuation is called [11], [12]. They can approach evacuees and guide them out of a building with no danger to emergency personnel.

Existing evacuation simulators have used models of human behavior in evacuations [15], [16], but thus far few have explored the possibility of robotic guidance [13], [12], [14] and none have examined human reactions to robotic guidance in an evacuation. To this end, we have created a three dimensional computer simulation of an emergency environment. Two emergency evacuation robots have been simulated in a fire emergency inside a mall environment. Seven total scenarios were created to determine how volunteers respond to different robots and actions. The simulator was created to be used as a Java Applet inside of a web browser so that it can be distributed to a wide audience. The decision to use a simulated environment that could be used in any web browser was motivated by several experiments using similar environments to perform human-robot interaction research [5], [9], [7].

II. Background

A. Exit Sign Design Constraints

To facilitate an orderly evacuation robot guides should be designed such that it is obvious they are pointing evacuees towards an exit. Considerable inspiration for the designs of the robots was taken from existing work on exit sign design. There is considerable debate about the ideal design of exit signs. A NIST report [6] confirmed some previous studies which found that luminosity is a large factor in visibility (some of their observers suggested it is the largest factor). Most of the results were inconclusive, with some observers preferring one particular style and others preferring another. The color red was preferred to green, however the authors mention that this could be due to a variety of reasons, including familiarity with the color and differing brightness.

Another study evaluated several different exit signs in use at the time, but did not reach many conclusions despite testing in normal conditions and smoke [10]. They determined that color, brightness and size of the sign mattered, but could only recommend that signs be as large and bright as possible. They found that exit signs in North America were usually red while those in Europe were usually green. Green signs typically allow for a greater luminosity, but easy recognition is also important, so the study could not give a firm recommendation on color.

Exit signs also must consider people with disabilities. This is one area in particular where robots could be a great benefit as they can approach those who have sight problems. A study was performed [3]where people in assisted living facilities rated the visibility of various exit signs. A sizable minority of these people had vision problems. This paper had some surprising results as it shows that there is a small difference between the distance at which people with seeing disabilities can recognize an exit sign (mean of 13.9-14.6 meters depending on the sign) versus those without seeing disabilities (14.5-14.7 meters). The study found that people can recognize an exit sign at a point several meters past where they can read the word. This confirms the idea that robots should use a familiar sign to guide people.

B. Exit Preference

Benthorn performed a study to determine which exit individuals chose in a simulated emergency [1]. Each volunteer was given a headset which played an alarm and gave instructions to evacuate an Ikea store as quickly as possible. The study found that when volunteers could see closed exit doors nearby they still preferred to go out through the front of the store, but when they could see an open exit door (such that they could see outdoors) then they were more likely to take it regardless of distance.

C. Search and Rescue Robots

Considerable research has been done on using robots for search and rescue applications. Bethel and Murphy studied how volunteers reacted to rescue robots in a simulated urban disaster [2], [8]. They created several recommendations for how robots should approach, contact and interact with the victims. For the approach and other motions, the researchers suggest using smooth acceleration and deceleration. In contrast, typical robots are usually jerky when moving in an unknown environment. The researchers also suggested using blue lighting around the robot to convey a sense of calm. For interaction, they note that there are several different "zones" where the robot can be: the intimate zone (0 to 0.46 meters), the personal zone (0.46 to 1.22 meters), the social zone (1.22 to 3.66 meters) and the public zone (further than 3.66 meters). Robots are assumed to stay in the social zone or closer. To communicate, the researchers assumed that the robots would have to be in the intimate or personal zones. They suggested using voice communication to reassure the victim and music when there is no information to communicate.

III. Related Work

The MIT Media Lab has experimented several times with video games as a method of "crowdsourcing" behavior learning. Orkin and Roy were inspired by early chatbots, such as ELIZA, to create a game to simulate interactions between two people in a restaurant [9]. Users would join the game and randomly be assigned as either a waiter or a client. Then they would proceed to interact as if they were in an actual restaurant. The researchers noted that users typically took the game seriously and acted as if they were in a real social situation. The results gave considerable data about what responses were given to typical prompts in the environment. Users were solicited through blogs, web postings, emails and social media. A total of 3,355 users played 5,200 games over several months and completed a survey afterwards.

Other research has expanded on crowdsourced data gathering. The Media Lab has created a second video game to help train a robot for a space mission [5]. The simulation sets up two users on a Mars base, one as the robot and one as the astronaut. No results have been published yet, but the data is planned to be used to teach an actual robot how to interact in such a situation. The planning algorithm from the restaurant game is proposed to be used to learn other temporal data, such as how humans interact with actual robots [4].

Other researchers have used games to gather data to improve game AI [7]. A Bayesian Model was created to learn how a user responds in a simple role-playing game. This allowed for more realistic AI players to be created.

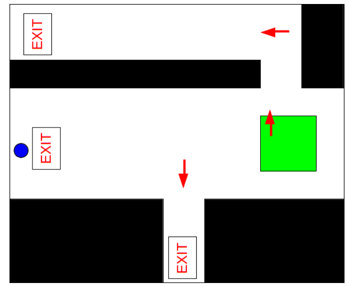


Figure 1: Map of the Mall Model. Exit signs indicate the location of exits. Red arrows indicate directional exit signs (and the direction they point). The blue circle indicates the starting position of the user. The green square indicates the highlighted region.

IV. Methodology

In our research, we have created a three dimensional environment to simulate an emergency and determine to what degree an individual will follow a robot to a variety of exits. The game engine used to develop the three dimensional simulator was jMonkeyEngine 3. This engine was chosen so that the simulator could be deployed in a web browser as a Java Applet. A small mall environment and two robot models were created in Blender. Test subjects started near the front entrance and were instructed to proceed to a highlighted region towards the back of the mall in their own time. Once the user entered this region smoke filtered into view and the interface displayed the text "FIRE EMERGENCY! EVACUATE!" This gave the users time to explore the environment before the emergency, as if they were in a real mall. The mall was left empty of people and obstacles to better study the effects of one individual in an emergency. All exits were marked with exit signs in front of the exit and in any hallway leading to the exit, as in a normal mall.

A. Environment Model

A small mall environment was created as the test model (Figure 1). Three exits were created to give the user a choice during simulations. The exits were each approximately the same distance from the highlighted region. Each exit was marked with exit signs at each corner. The front exit was just behind the starting position of the user (Figure 2). This gave the appearance of the user entering a mall through the main doors. Another exit was to the left approximately halfway down the main area of the mall. The final exit was along a corridor immediately to the right of the highlighted region. Without any additional guidance and with no smoke obstruction, the user is expected to move straight towards the large exit in front.

Some attempt was made to give the appropriate atmosphere to the simulator by adding storefronts and textures along the wall, floor and ceiling. A simple outdoor scene could be seen out of each door, along with some sunlight. A patterned texture was used on the floor and ceiling so that the user would have a sense of motion as the camera moved through the scene.

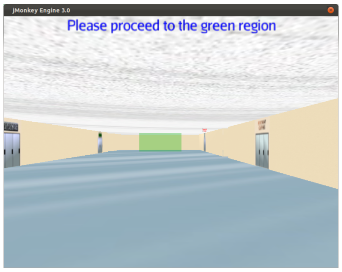


Figure 2: User view at start of simulation. Highlighted region is immediately ahead.

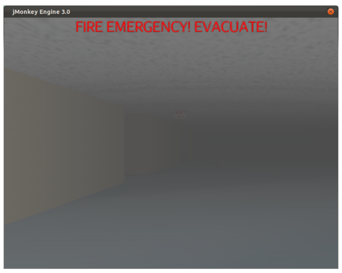


Figure 3: User view at start of emergency.

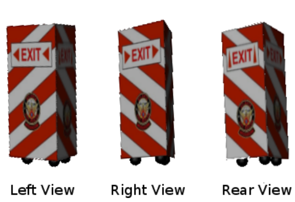
Smoke was added to the model by using the game engine's fog mechanism with a dark gray color. The smoke level was set such that walls were just visible across the large hallway. A view of the simulation after smoke was added is in Figure 3.

The user controls the simulator with the arrow keys. Up/down are used to traverse and left/right are used to turn.

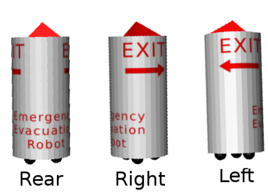
B. Robot Models

Two robot models were created with significantly different features in order to determine which features users best responded to in an evacuation robot. Each was used in three different scenarios to guide the user to each exit. Both models were developed in [11] by reviewing existing emergency egress research.

1) Robot 1: This robot (Figure 4a) is designed with three sides. The rear side is designed to be noticeably narrower than the other two so that the robot's forward direction is clear. The three sides of the robot are nearly identical, except for directional arrows. The robot is approximately as tall as an adult human so that it can be seen in a crowd.



(a) Robot 1 Model



(b) Robot 2 Model

Figure 4: Robot Models

The most important aspect of the design is the static display featured prominently towards the top of each side of the robot. This is shown in the diagram as a standard North American exit sign. All signs have directional arrows pointing towards the front of the robot. It is assumed that the front of the robot will always be pointing towards the best exit path.

To encourage trust, the robot is designed with red stripes to make it resemble a fire truck. The robot has a fire department logo on it to show that it is a piece of emergency equipment. It is assumed that these robots, should they ever be deployed in real life, will require some sort of fire department certification and approval.

2) Robot 2: A second robot model was created to be significantly different from the first robot (Figure 4b). The design of this robot was supposed to be more clean and calming than Robot 1. It is also meant to respond to initial criticism that Robot 1 looks too much like a static signpost.

The robot has "EXIT" written twice on either side of its cylindrical body with arrows pointed towards the front. There is a three dimensional arrow on top also pointing towards the front of the robot. "Emergency Evacuation Robot" is written along the back to make the robot's purpose obvious.

The white body color was chosen for visibility in dim conditions while the red lettering and arrows were to remind evacuees that this is an emergency situation.

C. Robot Behaviors

Both robots followed the same control policy. The robots were assumed to have a holonomic drive such that they could point towards the desired exit regardless of their direction of travel. Robots were given a list of targets at which to point for each exit scenario. The targets were set at each corner along the desired path and at the final exit. The robot could choose between five positions in front of the user: far left of the user's field of vision, middle left, center, middle right and far right. The robot chose whichever position was closest to the desired target and pointed towards that target. The robot endeavored to stay within the social zone of the user with a proportional velocity controller. The maximum speed of the robot was set at three times the maximum speed of the player.

D. Hypotheses

Our first hypothesis is that evacuation times will be faster with a robot present than without. Previous simulation results have shown robots to be effective in an emergency and we have specifically designed these robots and behaviors with that in mind [12], [13]. Our next hypothesis is that Robot 1 will be better received than Robot 2 in the survey results. Our intuition is that Robot 1 presents more of a sense of urgency to the user and thus is a better evacuation robot. We have included Robot 2 in this experiment to test this intuition. Our final hypothesis is that most users will follow the robot initially, but few (if any) users will follow every time. We expect that the first time the robot appears the user will follow it out of curiosity. Some users are likely to follow it several more times out of trust. Eventually, the robot will go in a direction that the user does

Table I: Scenarios

ID	Scenario
0-X	No robot appears
1-F	Robot 1 appears and instructs the subject to proceed to the front exit
1-L	Robot 1 appears and instructs the subject to proceed to the left exit
1-R	Robot 1 appears and instructs the subject to proceed to the right exit
2-F	Robot 2 appears and instructs the subject to proceed to the front exit
2-L	Robot 2 appears and instructs the subject to proceed to the left exit
2-R	Robot 2 appears and instructs the subject to proceed to the right exit

not think is safe, or the user will become fatigued with the test and proceed on his or her own course.

V. Experiment Procedure

Each user was asked to complete seven total scenarios, presented in random order (Table I). Volunteers were solicited by sending an announcement with a link to the interactive simulations via email. Volunteers performed the test on personal computers outside of a lab environment.

Each scenario ended when the user reached an exit. User and robot (when applicable) positions were recorded at 0.5 second intervals. The time at the start of the scenario, time at the start of the emergency and time when the user reached an exit were all recorded for each scenario. After all of the scenarios, users were given a short survey (Table II). All Likert Scale questions were rated on a scale of 1 (labeled "Strongly Disagree") to 7 (labeled "Strongly Agree). Only the extreme answers were labeled.

VI. Results

A. Scenario Results

15 volunteers completed all seven scenarios. Any volunteers who completed fewer than all scenarios were excluded from the results given below. As can be seen in Figure 5, every user followed the robot at least twice. Five users followed the robot in every scenario where a robot appeared. In general, users followed the robot for the first few scenarios and then tended to leave by the left exit. This is most likely because they were frustrated from running so many similar scenarios and perceived the left exit to be the closest from the highlighted region.

Three of the robot scenarios show a trend (p-value < 0.1 using a paired t-test) of allowing users to evacuate faster when robots were present (see Figure 6 and Table III). It should be noted that the averages include those users who did not follow the robot, so we expect that a larger sample size would allow us to find significant results that show that following the robot produces a faster evacuation. There are no statistically significant results for scenarios between robots (Table IV), but the results for the front and right exits show a general trend where evacuation is faster with Robot 2.

B. Quantitative Survey Results

All volunteers reported being male students between the ages of 20 and 32 (mean of 24). Users rated their level of comfort with technology at a mean of 6.1 and rated the trustworthiness of firefighters in an emergency at a mean of 6.9. Users rated the two robots as essentially the same on the Likert scale, with responses ranging from 5.1 to 5.6 on a seven point scale (Figure 7). Some users failed to respond to some questions (Figure V). It is unknown why the users failed to respond. The realism of the simulation was rated slightly lower with a mean of 4.7.

C. Qualitative Survey Results

Most of the open-field comments given were constructive criticisms to help improve the design of the robots and simulation. The most consistent critique was that the robot would often move past a nearby exit to guide them to a further exit. Most users realized this was by design as part of the

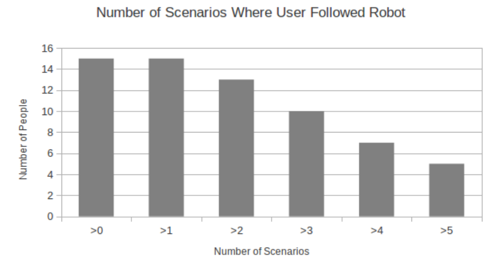


Figure 5: Number of Scenarios Where User Followed Robot

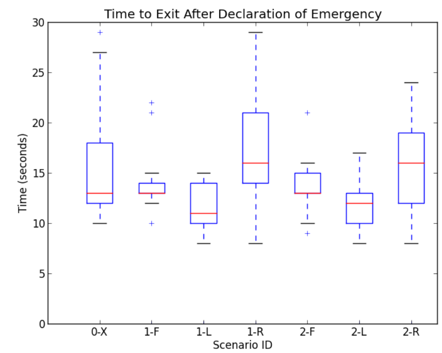


Figure 6: Average Time From Start of Emergency to Exit

Table III: P-Values Between No-Robot Scenario and Other Scenarios

Robot	Scenario	P-Value
1	Front Exit	0.287
1	Left Exit	0.029
1	Right Exit	0.166
2	Front Exit	0.073
2	Left Exit	0.052
2	Right Exit	0.911

Table IV: P-Values Between Robot Scenarios

Scenario	P-Value
Front Exit	0.174
Left Exit	0.859
Right Exit	0.116

Table II: Survey Questions

Label	Question	Response
Q1	In what year were you born?	Short answer
Q2	What is your gender?	Multiple choice
Q3	What is your occupation?	Short answer
Q4	I am comfortable with using new technology	Likert Scale
Q5	I believe firefighters are trustworthy guides in a fire emergency	Likert Scale
Q6a	Robot 1 [accompanied by picture] looked like a trustworthy guide.	Likert Scale
Q6b	How could this robot's appearance be improved to encourage evacuees to follow it?	Short Answer
Q7a	Robot 1 acted like a trustworthy guide.	Likert Scale
Q7b	How could this robot's behavior/motion be improved to encourage evacuees to follow it?	Short Answer
Q8a	I followed Robot 1.	Likert Scale
Q8b	Why or why not?	Short Answer
Q9a	Robot 2 [accompanied by picture] looked like a trustworthy guide.	Likert Scale
Q9b	How could this robot's appearance be improved to encourage evacuees to follow it?	Short Answer
Q10a	Robot 2 acted like a trustworthy guide.	Likert Scale
Q10b	How could this robot's behavior/motion be improved to encourage evacuees to follow it?	Short Answer
Q11a	I followed Robot 2.	Likert Scale
Q11b	Why or why not?	Short Answer
Q12a	During this simulation, I acted as if I were in a real emergency.	Likert Scale
Q12b	Why or why not?	Short Answer
Q13	What would make the simulation more realistic?	Short Answer
Q14	Is there anything else that would encourage you to follow a robot in an emergency?	Short Answer
Q15	Please list any other comments here	Short Answer

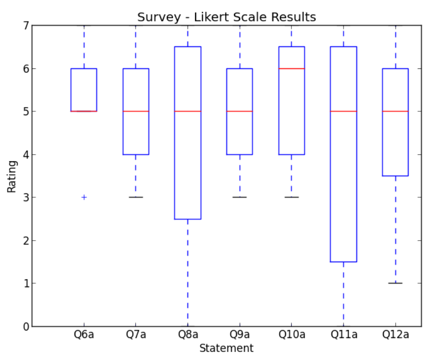


Figure 7: Survey Results

Table V: Number of Respondents Per Question

Question	Respondents
Q6	14
Q7	14
Q8	12
Q9	13
Q10	13
Q11	11
Q12	15

experiment, but suggested that the robot should give some reason for not going to the nearest exit. Several users suggested that including other evacuees would make the simulation more realistic. Five users suggested that a more complicated environment would increase the necessity of a robot guide. Six users said that they followed the robots until they understood the environment better, then took whichever way seemed fastest. One user suggested that some sort of scoring system could be added to encourage a fast evacuation.

Robot 1 was generally well received, but several comments were made for improving its appearance. One user commented that it looked like a "candy cane" and that it could be improved by adding explicit information that the robot was serving an emergency purpose. Several users suggested that lights or strobes should be included on the robot. Most users mentioned that audio notifications would help to increase the urgency of the emergency and help give guidance to evacuees. Three users specifically noted that the exit signs on the side of the robot encouraged them to follow it.

Despite its slightly higher score on the Likert statements, Robot 2 received more negative comments. Several of the comments about the addition of lights and audio were repeated. One user felt that the robot resembled a trash can. One user noted that the robot was easier to lose in the smoke, but suggested that adding some color to it would fix that. Several users mentioned that it was hard to tell which direction was forward, but some noted the same about Robot 1.

Two users mentioned differences in actions between the two robots despite their identical programming. One thought that Robot 2 was faster and thus more trustworthy. One thought that one of the robots (he did not specify which) was attempting to deceive him. Two users were confused because the robot turned too often. Four users noted that the robot lost their trust when it passed a clearly marked exit in favor of one further away.

VII. Discussion

Many of the comments given by the volunteers are being used to create the next revision of evacuation robot designs and behaviors. We are also planning several more scenarios to clarify some of the results.

A. *Robot Design*

There was virtually no difference in the quantitative reviews between the two robot designs, so both designs will be revised and tested again. This was something of a surprise, but because both robots received favorable reviews we anticipate that they both have features necessary in an evacuation robot. Efforts will be made to change Robot 1 so that it looks less like a "candy cane" and more like the tool of an emergency responder. A trial version will be made that is primarily red, with some reflective white patches. Similarly, Robot 2 will have features added to make it more distinctive in a smoke-filled room. Both robots will have some flashing lights added; however, this will have to be tested on a physical prototype to make sure that the lights are not bright enough to blind nearby evacuees.

Thus far, audio has been avoided in the simulation because there is no guarantee that users will have the speakers turned up on their computer. This could be solved by holding user testing on a lab computer, but the intent is to distribute the simulator to the public for future testing. In the future, some guidance suggestions by the robot may be added to the simulator in the form of speech bubbles.

B. Robot Actions

Several users complained that the robot passed obvious exits; however, that was intentional to determine how the user responds to robot guidance so it will not necessarily be changed in the future. Efforts will be made to have the robots move in a more definite way, possibly by increasing their speed and improving their path planning.

C. Scenario Revisions

The two largest complaints about the simulator were the repetitive scenarios and simplistic environment. In the next iteration of testing, we are hoping to attract enough users so that each user only has to complete one or two scenarios. With less time spent in the simulator the users will have less time to learn the environment, so a simpler environment will not pose as many difficulties. We will prepare new environments as necessary for future experiments.

When users ignored robot guidance they tended to exit through the left door rather than the front door. This does not agree with [1]; however, future testing will attempt to determine if the effect was simply caused by acclimation to the environment. The left exit is particularly attractive from the perspective of the highlighted region as there is an exit sign in sight.

VIII. Conclusions and Future Work

Our first hypothesis was correct in three of the six scenarios. In those scenarios, users evacuated faster with a robot present than without. Our second hypothesis was incorrect: users did not rate Robot 1 significantly better than Robot 2. Both robots received favorable reviews on the Likert scale questions, so both robots will be revised and presented in future studies. Surprisingly, one-third of all volunteers followed the robots whenever presented, so our expectations in hypothesis three were exceeded. While some of these results are certainly due to the novelty effect of evacuation robots, we are hopeful that the general public will accept these robots in the event of an emergency.

In previous work [13], we have found that a lower bound of 30% of evacuees and an upper bound of 80% of evacuees must trust guide robots in order to produce significantly better survivability in an emergency. While our current sample size is too small for solid conclusions, this experiment has found that all tested individuals are willing to follow the robot in at least two scenarios and 33% of those tested followed in all scenarios.

Future work includes new experiments to test revised robot designs as well as revised behavior. The next experiment will be made available to a much larger audience in an effort to find statistically significant results. Future experiments will also test how users respond to guidance suggestions after using the robot in a non-emergency situation first, e.g. as a tour guide robot or as a drink serving robot.

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