

Insect Telepresence:

Using robotic tele-embodiment to bring insects face to face with humans

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Abstract

The Insect Telepresence project combines expertise from the robotics and human-computer interaction communities to create a robot exhibit that enables telepresence in scale. The underlying mission of this work is educational: to promote appreciation for insect life and small-scale complexity through exploration of live insect colonies. In this article we describe the robot hardware and software used to bring students face-to-face with insects. We also summarize the formal HCI methods used to design and evaluate the Insect Telepresence robot. The complete working exhibit, now installed as a permanent robot-entomology station at the Carnegie Museum of Natural History, is presented in words and pictures.

Keywords: telerobotics, telepresence, robot manipulators, museum robotics

1. Motivation

The Carnegie Museum of Natural History (CMNH) has an invertebrate zoology department, featuring exhibitions of its collection of fascinating and exotic species of insects. A primary goal of the CMNH is to impart knowledge of the natural world to visitors. Hands-on and live exhibits in particular are used to encourage active exploration of the natural world, including non-human inhabitants of the planet. Currently, visitors only make a cursory examination of many exhibits because they are not provided with the appropriate tools to delve more deeply into the subject matter; they spend on average 5

seconds scanning exhibition contents. In an attempt to address the problem of shallow visitor investigation of exhibits, museums often provide docents or museum guides as a way to help visitors understand and gain meaningful insight into what is on display. However, it is not feasible for museums to provide a tour guide for every visitor and every exhibit.

Another interesting problem facing the CMNH, specifically the invertebrate zoology department, is that insects are fantastically complex organisms but most of this complexity is hidden from the naked eye. Most humans do not easily see the details of insect anatomy and behavior. This inability to see the insect structures is amplified by the fact that museum visitors cannot get close enough to the insect to examine it due to the physical constraints of display terrariums.

The Insect Telepresence project has developed a robotic tool that allows the visitor to enter the insect world and bridge the gap between inquisitive museum visitor and insect. Human-Computer Interaction techniques were used to research how the robot might be used in the museum and suggest designs for the interfaces between the museum visitor, the robot and the insects. Following the fabrication of a physical prototype, two experiments were conducted to evaluate the control and design decisions and the success of the robot as a tool to enhance visitor exploration and investigation. The final robotic Insect Telepresence system is now a permanent exhibit at the main entrance of the Carnegie Museum of Natural History. As of September 1999, the Insect Telepresence robot has been interacting with Madagascan hissing roaches, humans and scorpions for more than five months.

2. Insect Telepresence

Telepresence is often viewed as an advanced form of tele-operation, a technology that has been the subject of research for nearly fifty years (Goertz & Thompson 1954). The standard form of telepresence, telepresence in *space*, enables humans to interact with an environment that is spatially out of their reach. Often, this technology is proposed for applications involving environments that are hostile or unreachable for humans: outer

space, deep recesses of the ocean, radioactive sites, etc (Weisbin & Lavery 1994; Draper 1995).

A more recent development in spatial telepresence is tele-embodiment, whereby a human achieves telepresence in a familiar or comfortable human environment. Remote surgery has long been an important target application of this technology because the surgeon may be physically unavailable at the locale where surgery is required (Green et al. 1995). Embodiment for the sake of visual and auditory presence in a remote environment has been demonstrated by Paulos & Canny in the creation of Personal Roving Presences (Paulos & Canny 1998a, 1998b). Recently, our group has added this level of personal embodiment to a full-time robotic tour guide at CMNH (Nourbakhsh et al. 1999), enabling web visitors to tour the museum without actually travelling to Pittsburgh, Pennsylvania.

This project has a different focus: telepresence in *scale*. Our intention was to use robotics and optics technologies to offer visitors a new sense of scale, enabling exploration of an environment from the perspective of a small insect. The robot, therefore, acts as the embodiment of the museum goer, who gets to interact with insects on their own terms.

The Insect Telepresence project offered both HCI design challenges and robot hardware and software design questions: how should users manipulate the robot, how should the captured image be displayed, how *transparent* should the robot should be in the exhibition (should it be seen or simply enhance the user experience without making its presence known?), and should we protect the insects from the robot, and by extension, the museum visitor?

In this paper we will outline how the robot was built, what HCI experiments were conducted to answer these questions, and how those results have informed a new robotic exhibit that is now in daily use at the Carnegie Museum of Natural History. In Section 3, we will discuss the HCI background research and design solutions. Then, in Section 4 we describe the *Insect Telepresence* robot hardware and software. Sections 5 and 6 will describe the two experiments conducted with two versions of the robot, and the results of those experiments. Finally, we will offer our conclusions and future directions.

3. Initial HCI Research

This project relies heavily on technology, yet its underlying goal is human: to help people have a more meaningful museum experience. The field of Human-Computer Interaction provides formal techniques for addressing the interfaces between humans and technology. Current HCI practice focuses on user-centered design, which suggests that understanding the user and the tasks to be accomplished can lead to better design of the tool. A team of six HCI Masters Students at Carnegie Mellon University employed three HCI techniques to generate recommendations for Insect Telepresence and evaluate the ensuing prototype. This section summarizes the research and findings of the HCI team.

3.1 Contextual Inquiry

Contextual Inquiry and Design is a technique developed by Hugh Beyer and Karen Holtzblatt to understand how people use tools to accomplish tasks, and from this understanding to develop designs for building better tools (Holtzblatt & Beyer 1996; Beyer & Holtzblatt 1998). The specific aims of Contextual Inquiry and Design are to understand the task, the task environment and the user of the tool being designed. In this case we needed to understand how museum visitors use the invertebrate zoology exhibits, and how they use museum tour guides to enhance their experiences.

We conducted Contextual Inquiries with three staff members at the CMNH to get a broad understanding of the typical museum visitor and how they interact with the exhibits. We spoke with a teen docent in the invertebrate zoology division; a tour guide leading a *bug tour* for a birthday party; and the head entomologist for the Division of Invertebrate Zoology.

The teen docent inquiry was approached with three target questions:

- 1 *What kinds of interactions occur between visitor and insect?*
- 2 *What kinds of interactions occur between visitor and docent?*
- 3 *What kinds of interactions occur between docent and insect?*



Figure 1: Teen Docent contextual inquiry

Our belief was that understanding these interactions would aid in the design of a robot and an environment to facilitate visitor experiences in the same way that docents do. The interview and observation of the teen docent (see Fig. 1) led to five conclusions:

1. People have short attention spans, especially when reading label copy in an exhibit. People browsing spend approximately 5 seconds looking before moving on.
2. Opportunities to personally contact and examine the insect significantly lengthens the total interaction time.
3. Docents provide a more interactive and engaging experience, causing visitors to spend more time looking and learning.
4. People prefer live exhibits to displays of pinned insects.
5. The separation of visitor and insect by exhibition casing and glass makes it difficult for visitors to see bugs closely.

In hindsight these results are intuitive. An important secondary conclusion was that the effectiveness of the Insect Telepresence robot may be quantitatively measured by timing the average interaction time between visitors and the exhibit.

The second contextual inquiry was a *bug birthday party*, a special event offered by the museum, where a child celebrating a birthday can bring friends, take a tour of the museum focusing on insects and, for the finale, learn how to pin a grasshopper professionally. The purpose of conducting this observation was to note how docents deal with groups of

visitors, and how groups of visitors interact with exhibits. This observation led to a confirmation of one of the earlier conclusions and the addition of two new conclusions:

1. Docents provide a more interactive and engaging experience, causing visitors to spend more time looking and learning. (a confirmation of an earlier observation)
2. People are simultaneously drawn to and repulsed by the insects.
3. Kids were hesitant to touch initially, but it became a *cool thing to do* and they spent a great deal of time simply looking at the insects up close when the glass barrier was removed.



Figure 2: Interviewing John Rawlins, head of entomology

The final contextual inquiry consisted of an interview with John Rawlins, the head of the Division of Invertebrate Zoology (see Fig. 2). The interview was conducted to understand insect psychology issues, museum staff issues, and past experiences with technology and exhibitions. The department was aware of the potential for using technologies such as robotics in their exhibits and, importantly, these individuals had strong feelings about the potential negative impact of such technology.

As a robotic community considering installation of robot technologies throughout society, we must be keenly aware of these anti-technology feelings and their very valid foundations. After all, the final goal of human-robot interaction in this case is to improve the experience of the staff and visitors at CMNH.

Three conclusions were drawn from this inquiry:

1. Technology for technology's sake is not useful. It gets in the way of the point of exhibitions, which is to learn about the natural world.
2. Technical exhibits lose their appeal for visitors quickly if the exhibit lacks a *real experience*.
3. People come to a natural history museum to see the natural world, not technology.

Our conclusions, on the basis of the three contextual inquiries, were:

1. There is a need to increase the time spent looking in an exhibition. Visitors do not spend very long looking at exhibitions where much effort to interpret on the part of the user is necessary
2. People like assistance when looking at an exhibit. Docents facilitate the museum experience and cause people to spend more time looking.
3. People prefer live exhibits to the pinned ones. Opportunities to examine things personally and more closely increases time spent with an exhibit.
4. People come to the museum to learn and have meaningful experiences, and need a robotic tool to enhance that experience, not interfere with it.

3.2 Modeling

After conducting Contextual Inquiries, the team of HCI students proceeded to the next step in the Contextual Inquiry and Design process: modeling the environment. The team conducted an interpretation session to revisit the interviews and record what was learned in the form of pictorial models. Five types of models were created. *Workflow* describes the communication necessary to complete work. *Sequence* charts the actual steps necessary to complete a task. *Artifact* depicts the tools necessary to complete a task. *Culture* represents the unspoken aspects of completing a task, including policies, attitudes and values. *Physical* shows the physical layout of the work space.

docent CI : cultural model

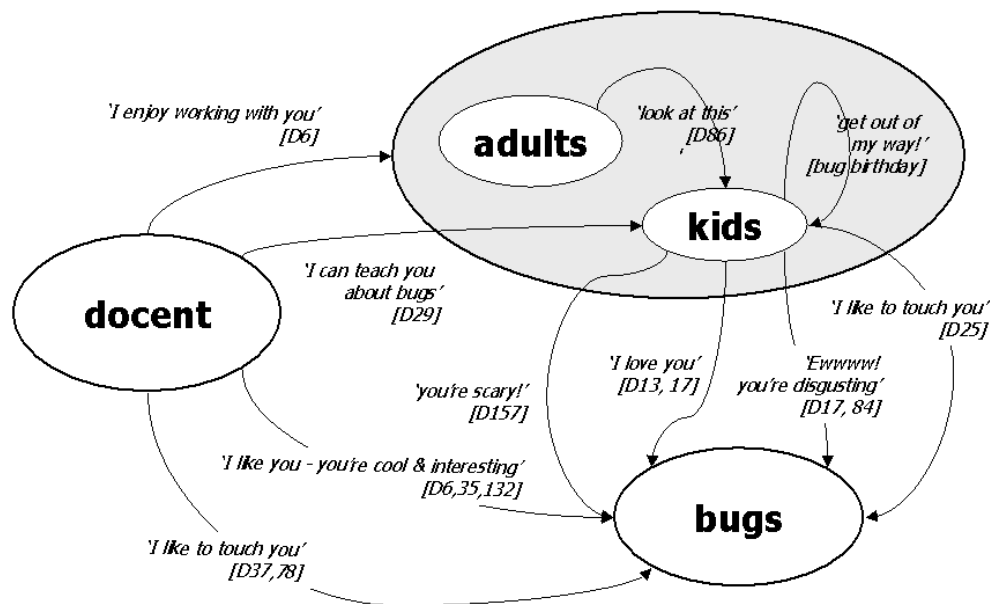


Figure 3: The teen docent and bug birthday party Cultural Model

The five models give five different perspectives of the task, and make it possible to comprehend the complexity of the task. The models are used to develop a common language between the various stakeholders of the project. Graphical representations of this common language reveal the patterns and structure of work in a far more concise fashion than would be possible through prose.

Figures 3 and 4 depict the two *Cultural* models based on the expert interview and the teen docent study. For instance, in Figure 3, the docent's attitudes toward the insects are wholly positive while the visitors' attitudes include elements of both extremes. Much of the success of the docent tour can be attributed to the docent's ability to modulate these visitor attitudes, reinforcing visitors' positive attitudes while filtering out negative attitudes. This is just what the robotic exhibit must also accomplish.

bug expert : cultural model

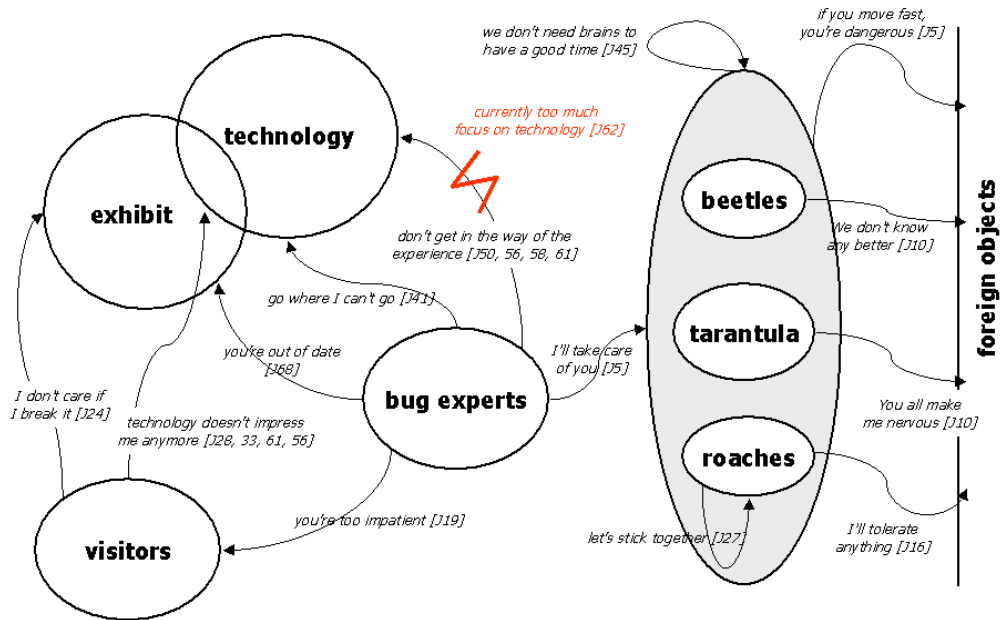


Figure 4: The expert interview Cultural model

Figure 4 depicts both the attitude of various insects at the possible existence of a free-roaming robot in their midst and the attitude of the bug expert with respect to technology. It is important to note that, although the bug expert is aware of the potential negative consequences of technology, he is also well aware of its advantages (e.g. *go where I can't go*). The modeling process was invaluable in transforming the bug expert from a hesitant member of the team to a champion for Insect Telepresence throughout CMNH.

3.3 Heuristic Evaluation

The HCI team employed a third technique for evaluating the usability of human-technology interactions to develop design solutions: Heuristic Evaluation. The technique requires usability or domain experts to evaluate an interface to judge its compliance with recognized usability principles, or heuristics. The principles used in these evaluations were

developed by Jakob Nielsen (Nielsen 1994; Nielsen 1993). Two examples of recognized usability heuristics are:

Visibility of System Status: The system should always keep the users informed about what is going on, through appropriate feedback within reasonable time.

Match between system and the real world: The system should speak the user's language, with words, phrases, and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

Each usability expert reviewed the interfaces independently, and the results were gathered and merged into one report. The report also reflected the team's observations with regard to the frequency and criticality of the heuristic violations found. The usability study was conducted by evaluating a technology in place at CMNH that most closely resembled *Insect Telepresence*. The conclusions of the study could then be used when designing and fabricating the robot exhibit.



Figure 5: The remote surveillance kiosk located on the first floor.

The chosen technological artifact was a surveillance camera remote control. The camera, installed on the third floor of the museum, can be controlled from a kiosk on the first floor (Fig. 5). The third floor camera image is projected on a large screen television, with four buttons on the face of a stand to control the rotation of the camera and the focus

of the camera. In museums, there is an exponential decrease in visitor attendance with each successive, higher floor of the building. The purpose of this kiosk was to attract visitors to the third floor artifacts so that they would take the time to travel two floors up.

The conclusions of the heuristic evaluation were:

1. The kiosk buttons did not readily communicate their use, making the device unintuitive and difficult to use.
2. Because the interface was not intuitive, they needed to have labeling or directions for their use. Few or no directions were provided to assist the user in understanding how to interact with the device, or what steps were needed to be successful in using the device.
3. Four buttons in a row to control left and right rotation and zoom in and zoom out functions do not match the user's idea of how to operate a camera.

The lessons learned for application to *Insect Telepresence* are obvious: signage and input devices must be chosen with care in order for visitors to feel readily comfortable with the robot system. Since users do not have significant preconceptions concerning control systems necessary for interacting with robots, particular care must be taken in the first design of such an input device.

4. The *Insect Telepresence* Robot

Based on the HCI formative evaluations, it was clear that good human interface design for the Insect Telepresence robot would be critical to its success. But a second, equally important observation was that users would try to physically manipulate the environment in order to hit the insects. The final goal was to design a robot that would require no supervision during operation. In summary, the key design requirements were long life, an easy to use input device, robustness to user abuse and robustness to user attempts to damage the insects and robot.

At the same time, a number of optical solutions were considered to bring high-fidelity images of the terrarium to the user station. Laparoscopic equipment, although of high fidelity, requires extremely high-intensity lighting and has a prohibitive price. Popular single-board cameras suffer both from poor lumens sensitivity and coarse pixel resolution.

The resolution of the CCD chip would be critical because of the effective magnification caused by projecting the image onto a 35" video monitor.

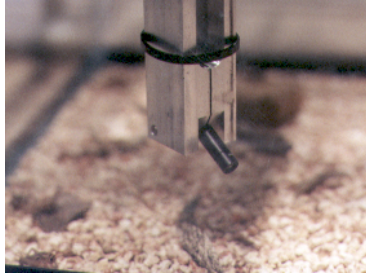


Figure 6: The Toshiba micro-camera remote head

The Toshiba remote head camera system was chosen for its extremely small head size (5 mm x 30 mm) and lumens sensitivity (Fig. 6). The camera head houses only the lens and CCD chip. The digital signal is carried through a tether to a NTSC conversion box, which produces a video signal appropriate for the monitor and provides auto-gain and auto white balance controls.

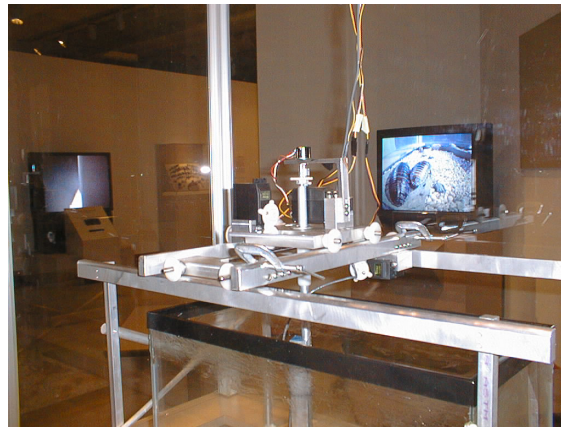


Figure 7: The robot raster, with the video display in the background

Once the camera was chosen, a tether was clearly needed, obviating the challenge of designing a standalone robot capable of walking or rolling on the terrarium surface. Furthermore, placing the camera above the insects, canted down, would provide the illusion of navigating at their level while guaranteeing that no insects would be squashed. The robot that resulted from these design considerations is a XY-type raster with a camera

mast that hangs down from above (Fig. 7). Camera angle in the *theta* direction would be controlled by rotating the entire camera mast from above.

In order to afford both high reliability and ease of service, drive motors were chosen as quarter-scale, internally geared high torque hobby servos (Hitec, Inc.) normally used in large-scale remote-control sailboats. These servos are designed for approximately 120 degrees of total travel. To overcome this obstacle, the X and Y servos were disassembled to remove the rotation stops and disconnect the feedback potentiometer. This transformed the X and Y servos from standard position-control devices to velocity control devices (Fig. 8). Any offset from the current potentiometer setting would cause the servos to rotate continuously, with a small amount of speed variation depending on the disparity between the commanded potentiometer position and the current potentiometer position.

Because the camera mast housed the video tether without the use of a slpring, it was critical that the rotation servo be limited to a finite number of turns in each direction. This was accomplished by removing the internal feedback potentiometer in the rotation servo, then replacing it with an externally mounted, 3-turn potentiometer. The upright servo and the potentiometer, mounted above it, can be seen in Fig. 8. Thus, the rotation servo remained a position control servo, albeit with far greater range of motion (1080 degrees) than originally intended.

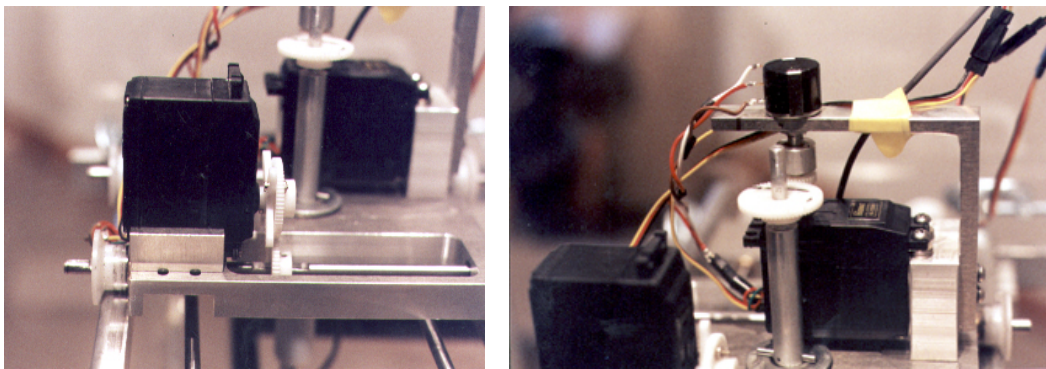


Figure 8: The X servo is shown at left (left) and the rotational servo is shown with feedback potentiometer positioned from above (right)

Although the robot mast is intended to be manually positioned high enough to just clear the insects, a failsafe mechanism to avoid damaging the camera and insects would still be required, since the insects will at times climb the glass walls of the terrarium and climb on one-another. The solution was simple, based on the fact that the camera mast is a fairly long lever arm, exerting a significant tilting force on the raster assembly. This tilting force would disable low-friction wheels from engaging the tracks, and so the wheels were machined smooth. The smooth lucite surface of the wheel engages the steel tracks with just enough force to carry the assembly; any force exerted on the camera stops the entire robot in place (Fig. 8).

The final requirement for robot design and fabrication involved control. The servos were commanded by an SV203 interface board (Pontech, Inc.) commanded by a standard 68HC11 board (Midwest Micro-Tek, Inc.). The microprocessor reads the joystick input values and the camera's angle, then computes a coordinate derive speeds to command the X and Y servos for camera-relative motion. In other words, *forward* on the joystick always corresponds to forward motion of the camera head by sending appropriate commands to the X and Y servos of the raster frame.

The basic input-out control and coordinate transform loop was written in C, compiled and placed on an EPROM on board the 68HC11, enabling museum staff to reset the software simply by power cycling the system.

5. Laboratory Experiment

A robot prototype was developed in November of 1998 which allowed the HCI team to conduct a round of user studies to examine how people would use the Insect Telepresence robot. The prototype behaved much like the final robot system described in Section 4; however, the servos and construction materials used were lower quality and less expensive (i.e. wood instead of steel, standard R/C aircraft servos in lieu of quarter scale servos).

A controlled experiment was conducted in the Mobot Programming Lab at Carnegie Mellon University (see Fig. 9). The prototype input device was a four-channel transmitter for R/C aircraft, with two two-axis joysticks. One joystick was used for camera-relative X/Y axes of motion, and a rotary knob was added for rotational position control. The

knob was a one-turn potentiometer whose position corresponded directly to an angular command for the camera. The second joystick was unused. Note that, in this instantiation, the X and Y degrees of freedom were controlled via velocity control while the rotational angle of the camera was controlled through position control.



Figure 9: Experimental laboratory setup

The camera image was projected on a 12 inch color monitor, and the terrarium was placed approximately 4 feet away from the monitor to see if users could navigate by simply looking at the monitor, and without looking at the terrarium.

The HCI observation technique used was the *Think aloud* usability study, in which users are asked to use a tool and complete a series of tasks and tell the observer what they are thinking while using the tool (Nielsen 1992). The usability professional records and observes the users responses and actions, without talking or interfering with what the user would naturally do. By not offering help until the user has reached an impasse, the observer can discover what kinds of problems people may have using the tool in the real-world scenario.

In this experiment 5 adults and 4 children were given the same series of tasks and asked to perform them with the robot prototype. The study began with the camera facing one of the short walls of the terrarium, looking out into the lab. The following script was used:

1. *Navigate through the terrarium with the joystick and knob controls*
2. *This terrarium contains Madagascan hissing cockroaches. Find one.*
3. *Roaches get thirsty running around the terrarium. Find the roaches' water bottle*
4. *Roaches eat all kinds of things. Find some of their food.*

5. *Sometimes the roaches get into fights. Find the roach with a broken antennae.*
6. *Now you know your way around the terrarium. Explore!*

Each observation took approximately 1 hour to complete. Results of the five observation periods were:

1. All but one user asked about or attempted to squish bugs and hit other objects with the device.
2. All users were able to eventually navigate with two controls, although they used them one at a time, not simultaneously.
3. All users spent time looking at the insects and remarked how interesting they were, and how wonderful it was to see them close up.
4. People were able to understand navigating with camera coordinates, with little adaptation time needed.
5. All the users remarked that they wanted to see how other bugs and animals looked through the camera.
6. Users want vertical movement of camera.
7. The rotation control knob was too sensitive for some of the user: they often overshot the distance they wanted to turn.

The design solutions that evolved from these observations were:

- Provide a single control device that has smoother movement.
- Remove the tank from view of the user.
- Create a complete environment for the experience.
- Design the robot so that users cannot hurt the insects or the robot.

6. Museum Experiment

A steel version of the Insect Telepresence robot was fabricated for installation at the Carnegie Museum of Natural History's main entrance area (see Section 4 for robot details). Museum grade exhibition cabinetry was designed, constructed and installed to

house the robot and the insects, and to provide an environment for the Insect Telepresence experience, following a conclusion from the Think Aloud Study.

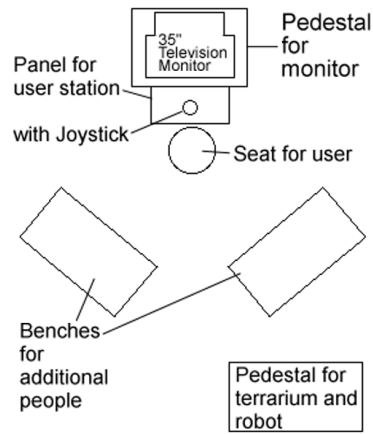


Figure 10: Overhead drawing of the display and cabinetry setup

The user station was constructed to place the visitor directly in front of (24-34" distance) a 35" high-quality color monitor which receives the camera image. A three-axis electric wheelchair joystick was installed, providing X and Y deflection on a single stick, topped off by a spring-loaded rotating knob at the tip of the joystick. The rotation control was used as a velocity controller of the camera's rotational position, as this knob had return springs and could not be used for position control.

People often come to the museum in groups, so benches were provided to accommodate and encourage spectators for the installation. The robot and terrarium were placed behind the viewer for two reasons: (1) to encourage concentration on the screen without the distraction of the sound and movement of the robot, and (2) as a way to visually draw people into the exhibit. The robot is visually engaging; many curious visitors were taken by its mechanical complexity, then moved on to the driving station to drive the robot.

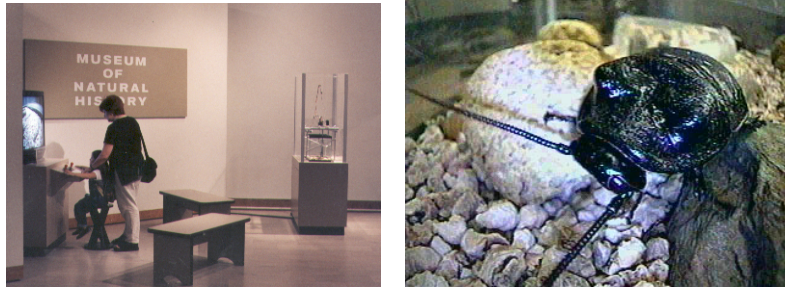


Figure 11: Photograph of the Insect Telepresence installation and the user's perspective

After installing the new robot and supporting hardware, user observations were conducted on three afternoons, over a period of seven hours. Users are defined as anyone who interacted with the installation, whether manipulating the robot, or simply watching the video display or vitrine. If a person participated in the installation for a period of at least 10 seconds, he or she was characterized as a user.

At the time of the observations, there was no signage or directions for use of the installation. The goal of monitoring museum visitors as they use Insect Telepresence was to discover if people could understand how to use the robot without assistance, and to take note of what people's natural inclinations are for use of the robot. Measurements and observations follow.

Number of Users

The total number of users observed: 204

Number of single users: 41 (~20%)

Number of users in groups: 164 (~80%)

Total number of user groups: 51

Average group size: 3 users

Most of the people engaging Insect Telepresence did so in groups. This can be attributed to how people visit museums, or that the age group that uses the exhibit tends to visit museums in groups. An interesting facet of the Insect Telepresence robot is the fact that it is visually appealing both at the control station and at the vitrine, where the robot and insects can be seen from above. This naturally leads to group

activities, where members of the group work together to use the controls and observe the results at the vitrine.

User age

Average age of users: 19.5 years

Three modes: 8 years, 10 years, and 35 years

Although the average age of the user indicates a late teen, a histogram would indicate three modes in the range of users, with the ages skewed to the younger segment of users. Much of this can be attributed to the particularly high attention given to the exhibit by children who are accompanied by parents. A fascinating observation was that the Insect Telepresence robot engaged both the very young children, who immediately controlled the robot motion from the joystick console, and the young parents, who would also take a turn at piloting the robot.

Time on Task

Average time on task of all users: 60 seconds

Average time on task of a single user: 27 seconds

Average time on task for user groups: 93 seconds

These results are pleasing in comparison to the five second average time that visitors will often spend inspecting an exhibit. The Insect Telepresence exhibit engages visitors successfully. Note that the single user spends decidedly less total time in the installation than a group of users. Taking turns with friends can account for the difference in use time, as can play and exploration patterns based on working with other members of the group.

Additional Common Tasks

Looking between the monitor and vitrine while moving joystick: ~55 users (~27%)

Looking at people on the Monitor with camera: ~39 users (~19%)

Constant motion while driving: ~42 users (~21%)

There were a few common tasks that prevailed across all the users. All users were able to make use of the exhibit's primary mission, navigating using the image on the monitor as their visual guide to explore the insects. However, about 27% of those controlling the robot also looked at the vitrine during robot motion. Our hypothesis is that a person likes seeing that he is affecting the physical robot system with his control input. The vitrine is far enough away and the terrarium is high enough that users cannot navigate by looking back (indeed, the joystick's reference frame is camera-based, and so physical navigation by viewing the robot is extremely difficult).

Another common action was to keep the robot in constant motion while in control. About 21% of those using the Insect Telepresence robot view kept the robot in constant motion. Our theory for this action is that the users are engaged by the motion. The color monitor is extremely large, and so continuous motion is visually stunning to the point that motion sickness is possible. Those behaving this way seem to spend little time actually looking at the bugs, and more time driving like a video game.

Using the robot to look outside the terrarium at friends was another popular activity. Several groups shared the tasks of aiming the camera to look at friends and making faces for the screen.

Of those people who were alone when using Insect Telepresence, 41% participated by looking at the vitrine and watching other people use the robot. The remaining 59% of the single users also engaged in driving the camera.

Other Observations

Many users said aloud that the joystick controls the camera in the vitrine. There were ten instances where users verbally made the connection between moving the joystick, seeing the image change on the screen, and the movement of the robot in the vitrine.

Visitors were clearly engaged by Insect Telepresence, spending a significant amount of time studying the insects and interacting with the robot. Of particular interest is the

connection made by visitors between their actions at the control station and the motion of the robot system in the vitrine. Recall that there was no signage hinting at this control aspect; and, furthermore, the control station and the vitrine were separated by approximately fifteen feet. This form of discovery was especially pleasing, as the visitors would grasp their potential for exploring the insect world and, at the same time, would appreciate the manner in which a technological artifact, the robot, was aiding them in this journey.

The Insect Telepresence robot has been operating continuously as of May 1999. It has operated in excess of 1000 hours as of September, 1999. The robot hardware has suffered one failure: the second rotation gear (Fig. 8) slipped vertically, requiring adjustment and tightening. The joystick, however, has been destroyed three times by visitors who deflect it with a great deal of force. After the third such event, the single, 3-axis joystick was replaced by two arcade-quality 2-axis joysticks that are designed to withstand roughhousing. Since that replacement was made, there have been no further system failures.

7. Future Work

Even without signage, Insect Telepresence engaged people and created new forms of interaction between insects and people. Visitors were able to sit down and have fun even without a great deal of direction. Most of the users were able to use the joystick successfully, including discovering the rotation aspect of control. This ease of use may be attributed to the predominantly young population of users who are video-game savvy, or to the fact that a joystick affords moving around, therefore driving.

Providing more signage will help users make the connections between the vitrine/robot and the user station. Our next steps for the project include developing an activity book that will increase the time on task for the individual user by providing directed challenges for users during their exposure to the terrarium (see Fig. 12).

**Everything's Coming Up Roaches
A Guide to Cockroach Behavior**



Hello there. Allow me to introduce myself. I am Jerry LeRoach (or something). I am a Madagascan Hissing Cockroach. Want to know what makes bugs like me tick? Pardon the pun. Use the Bug's Eye Viewcam and let me give you the cockroach grand tour!

Figure 12: Cover art for the activity book for Insect Telepresence

The activity book will offer all users opportunities to look more closely at the contents of the terrarium, slow down the rate of speed for driving, and hopefully, engender greater empathy for the roaches, diminishing the *Ew Gross!* comments and increasing the *Wow Cool!* remarks. The interest level generated in the robot has led us to also plan an additional set of activities and information cards that focus on the robot, which is a display in its own right.

7. Conclusions

The Insect Telepresence robot is a successful mechanism to help museum visitors engage with the living exhibits at the Carnegie Museum of Natural History. Telepresence allows humans to enter the small-scale world of insects. The robot is a useful tool for learning more about insects by removing barriers to actually seeing what the insects look like and increasing the time spent looking at the exhibit. In addition, observing the insects in their daily life creates empathy for other life forms.

The robot allows the visitor to act as his own tour guide by offering the visitor control over what he sees. As this exhibition continues, and suggested educational materials are added, the visitor will be even better able to understand what he is looking at, and tailor the investigative experience to satisfy his curiosity about the fascinating and complex world just out of sight. The better able the Insect Telepresence robot is in supporting the

visitor experience of examining and learning about the natural world, the more successful this venture will be.

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