
A Mixed Reality Approach to Human-Robot Interaction

First Author

James Young
University of Calgary
2500 University Drive NW
Calgary, AB T2N 1N4
jyoung@cpsc.ucalgary.ca

Second Author

Ehud Sharlin
University of Calgary
2500 University Drive NW
Calgary, AB T2N 1N4
ehud@cpsc.ucalgary.ca

Abstract

This paper offers a mixed reality approach to human-robot interaction (HRI) which exploits the fact that robots are both digital and physical entities. We use *mixed reality* (MR) to integrate digital interaction into the physical environment, allowing users to interact with robots' ideas and thoughts directly within the shared physical interaction space. We also present a taxonomy which we use to organise and classify the various interaction techniques that this environment offers. We demonstrate this environment and taxonomy by detailing two interaction techniques, *thought crumbs* and *bubblegrams*, and to evaluate these techniques, we offer the design of an implementation prototype.

Keywords

Mixed Reality, Human-robot interaction

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: User interfaces---Input devices and strategies, Interaction styles

Introduction

Robot technology is advancing steadily, and some believe that a robotics revolution is upon us[7]. As such, it is important that we understand the various

issues and problems surrounding HRI and develop effective interfaces to work with robots. Current HRI interfaces often fail to acknowledge that robots are simultaneously both physical and digital entities, and this separation of interaction spaces can hinder communication between humans and robots[2]. MR offers one solution to this problem by augmenting parts of the physical world with computer data (commonly accomplished using projectors or head-mounted displays (HMDs)), allowing a human user to interact with the digital information directly within their physical interaction space. Combining the physical and MR interaction spaces, this provides an environment which the humans and robots can use to interact. We call this environment the MR Integrated Environment(MRIE)¹

Given that robots are generally autonomous and mobile, they have a very large and dynamic physical interaction space. With the MRIE, we offer an environment which allows robots to utilise this space both physically and digitally, resulting in an extremely flexible interaction environment which robots can use to express their digital ideas and thoughts.

There are many possibilities for human-robot interaction within the MRIE. As a method of organising this, we introduce a taxonomy of the MRIE which we use to classify and compare various interaction techniques. This taxonomy maps the MRIE into four variables: *virtuality*, *lifespan*, *ownership*, and *activity*. To demonstrate the use of this taxonomy, two MRIE interaction techniques (*thought crumbs* and *bubblegrams*) are presented. Furthermore, we detail the design for a preliminary prototype which we will use

to realise and evaluate the ideas and techniques presented here.

Related Work

MR has been used as a means of combining digital information with the physical world for various applications, including animating storybooks[1], controlling robots[5] and assisting with medical surgery[3]. Most MR techniques can be classified as either using head-mounted-display (HMD) visualisation or projective visualisation. HMD visualisation offers portability and flexibility, given that they are often light weight and can be connected to a wearable computer. However, HMDs may constrict the user's vision due to a poor field-of-view and low resolution. Projective visualisation, on the other hand, can be integrate seamlessly into a user's entire field of view, allowing the user to fully use their natural vision. The downside, however, is that projectors are generally less portable than HMDs and they require a projection surface and appropriate lighting to work well.

There has been work on organising the wide range of interaction techniques offered by MR. For example, Milgram and Kishino map MR interaction to a taxonomy which classifies techniques as somewhere between the pure physical environment and a complete virtual environment[6]. The literature offers other taxonomies, such as a taxonomy for multi-robot systems which uses task type and criticality for classification[10].

While *mixed reality* has been used for various interaction applications, there has been a limited amount of work using *mixed reality* for HRI. In relation to this work, our MRIE is unique in that it offers an integrated digital and physical environment to be

¹ pronounced *merry*

shared between humans and autonomous robots. We also offer a taxonomy for the MRIE, similar to other taxonomies offered; Milgram's taxonomy is simply a single category within our taxonomy. Just as Milgram's taxonomy of MR offers a clear way to categorise various MR interaction systems, our taxonomy expands this and offers similar benefits for analysing MRIE interaction techniques.

The MRIE deals primarily with humans and robots interacting in a shared physical space and so portability and flexibility are very important aspects of prototype plan. As such, our prototype plan incorporates the use of HMDs for the *mixed reality* interface.

A Taxonomy for the MRIE

Our taxonomy maps the MRIE into four key variables, *lifespan*, *ownership*, *activity*, and *virtuality*, providing criteria which we use to describe MRIE interaction techniques.

The *lifespan* variable determines how long instances of a MRIE interaction technique last. For example, a robot may place a permanent MR element into the environment for information purposes, resulting in an arbitrarily long or permanent *lifespan*. On the other hand, a robot may display a surprise mark which is designed to disappear soon, resulting in a very short *lifespan*.

The *ownership* variable determines which robot in the MRIE, if any, owns the technique instance. This variable also includes partial *ownership* by other entities in the environment, so that entities in the environment may have control to alter instances created by a different

entity. The owner robot can decide which other entities can view or edit aspects of a technique instance.

The *activity* variable determines how active an interaction technique instance is, including the level at which it attracts attention and how it responds to interaction. An example of a technique with very low *activity* is a MR element which displays a static decoration on a wall; this technique does not actively invite attention, and does not react to interaction attempts. An example of a technique with high *activity* is a MR interactive menu system which incorporates three dimensional animation and sounds for interaction purposes.

The *virtuality* variable is based on Milgram's taxonomy and the *virtuality continuum which he uses to represent it*[6]; it categorises the representation technique as somewhere between purely physical and purely virtual. A purely physical technique could involve physically touching a robot, while a purely virtual technique could be to use virtual reality to control a robot.

Interaction Techniques

This section presents two techniques within the MRIE, *bubblegrams* and *thought crumbs*, illustrating how the MRIE and taxonomy can be used.

Bubblegrams

Bubblegrams are MRIE interaction techniques which are based on comic-style thought and speech bubbles, with the idea that they represent a robot's thoughts and expressions. They use MR to overlay the bubbles onto the physical interaction scene, floating next to the robot which generated it. *Bubblegrams* can also be interactive, offering interfaces such as status displays

or system menus, resembling an interactive physical display.

Lifespan: *Bubblegrams* are designed for short-term and specific interaction, and are generally not used for long-term tasks. For example, a surprise *bubblegram* floating over a robot's head may last for five seconds.

Ownership: Following the comic-style bubble motivation, *bubblegrams* have a single owner and are represented as being spatially attached to the owner in the MRIE interaction space.

Activity: While interactivity is not implied by the thought bubble motivation, *bubblegrams* offer a wide range of *activity*, ranging from a static graphic with no interactivity to a full-fledged animated and interactive menu.

Virtuality: *Bubblegrams* have medium *virtuality*, since they can actively bring complex digital data into the user's interaction space.

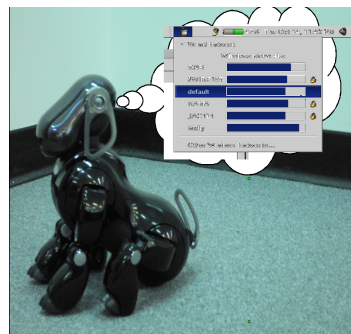


Figure 1: Artistic rendition of a *bubblegram*

Thought Crumbs

Thought crumbs, inspired by bread crumbs from the children's story Hansel and Gretel, is an interaction technique which uses pieces of digital information to represent a robot's thoughts or observations. These *thought crumbs* are left behind in the MRIE by virtually attaching an MR element to specific physical locations. For example, search and rescue robots may use *thought crumbs* to leave information such as temperature levels at particular locations.

Lifespan: *Thought crumbs* can have a *lifespan of any length*. A short-lived *thought crumb* may be a note left by a cleaning robot after cleaning a floor to say that the floor is wet; this *thought crumb* would expire after approximately ten minutes. A long term *thought crumb* could be a set of directional arrows left by a robot to direct a flow of traffic. These arrows would possibly be left until explicitly destroyed, possibly weeks later.

Ownership: *Thought crumbs*, once placed, are public elements within the shared environment and have no owner. Being an independent MR element, any entity within the space has full access to modify or destroy the element. For example, a cleaning robot may destroy *thought crumbs* which marked the areas it had to clean, or a human may remove *thought crumb* notes left behind by a cleaning robot.

Activity: *Thought crumbs* generally offer little to medium *activity*. Interactive *thought crumbs* only give basic expansions on the data already presented. An example of an interactive *thought crumb* could be a box which displays a bit of text, with scroll bars on the side to scroll through the text. The *activity* of the *thought crumb* can also be dependent on its age, such that the

age is conveyed to human users. For example, an old thought crumb may look wrinkled, faded, or rusty.

Virtuality: *Thought crumbs* have medium *virtuality*, as they actively use the virtual techniques to convey information.

Applications

Imagine a futuristic human and robot collaborative search and rescue team which uses the MRIE as a versatile and dynamic interaction environment. As the team enters a burning building, the robot team members rush ahead, surveying the building and leaving behind MR *thought crumbs*. These *thought crumbs* augment the vision of the humans, suggesting routes to take and highlighting various observations along the way. These observations include locked icons on doors which the robots found to be obstructed or skull and cross-bone poison icons representing dangerous gas levels. Finding a human survivor or victim, a robot notifies the human team members, and the humans can follow the particular robot's *thought crumbs* directly to the person. Upon encountering a human team member, a robot can display a

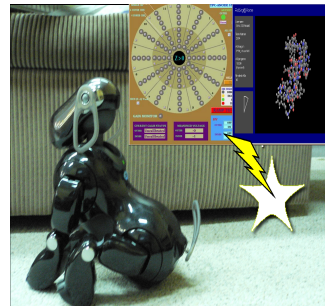


Figure 2: Artistic rendition of a *thought crumb*

bubblegram to the human, popping up a MR system menu which can be used to get status information about the robot or to give the robot commands. Humans can also issue queries to the robot, to get information about other robots or vital signs of a survivor, and will receive live results in an active *bubblegram*. This scenario does not use the decorations interaction technique because decorations are for long-term static elements, whereas the search and rescue team will not likely frequent the same rescue locations.

Preliminary Prototype

In order to build a working prototype which uses the MRIE, we have selected an Icuiti DV920 HMD and a Toshiba tablet PC in combination with a Sony AIBO robot dog as our MR platform. Next, computer vision needs to be used to identify AIBOs and locations in space for our interaction techniques. We will use an object recognition technique[9] in combination with a pre-mapped and tagged environment as our interaction space. The tags in the environment simulate points which entities would use for the interaction techniques. We have already successfully implemented this technique for AIBO detection.

Thirdly, an input method must be implemented which allows human users to interact with the MR elements. We are currently using the tablet interface, but will explore alternatives. Finally, a framework will be created to implement the shared MR space. We have designed a central network server which will be used by all entities within the space. Once implemented, this prototype can be used to evaluate the MRIE and presented techniques.

Future Work

The immediate future work is to finish the prototype implementation, and to evaluate the MRIE techniques presented. A comprehensive evaluation criteria must be developed as a means to compare the particular techniques. From here, various user studies will be conducted to test the system using the evaluation criteria.

There is room to add depth to our taxonomy, breaking each existing category into multiple, more narrow, categories. For example, the *activity* variable could be broken down into *response to interaction* and *representation technique*.

Entity-independent MR elements, such as *thought crumbs*, reside within the MRIE. It would be interesting to embed AI into these elements to create agent-like entities which reside purely within the mixed reality portion of the MRIE, just as humans reside purely in the physical portion and the robots reside in both.

Conclusion

Robot technology is advancing steadily, and it is important that we understand the various issues and problems surrounding interaction with robots. The fact that robots reside and interact in both the digital and physical worlds introduces interesting interaction challenges. To meet these challenges, we propose a solution called the MR Integrated Environment (MRIE) which provides a virtual environment of graphics and sound integrated directly into the real world. Using mixed reality, this environment allows a human user to interact with a robot's ideas and thoughts directly within the shared physical interaction space. We also

offer a taxonomy of the MRIE as a method of classifying the various interaction techniques that the MRIE offers. We demonstrate the MRIE and taxonomy through the introduction and discussion of two interaction techniques, *thought crumbs* and *bubblegrams*, and the mapping of these to the taxonomy. This paper also presented a design outline of a preliminary prototype which, once developed, can be used as a platform for evaluating various MRIE techniques in practice.

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