Design Interactions between Robot Surfaces and Human Designers

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ABSTRACT
This paper presents the rationale and current progress of my Ph.D. dissertation: "design interactions between robot surfaces and human designers." This specific topic serves as a case study trying to explore the question of how to design an interactive and partially intelligent space. We proposed the concept of "space agent" defined as "interactive and intelligent environments perceived by users as human agents" based on communication theories. Built upon this concept, we proposed a design framework for interactive environments. Then we further explored literatures about what space agent could contribute to human users specifically for the case of interior designers' work space. Research questions and research designs are introduced in this paper, followed by the discussions of experiments design.

Author Keywords
Space agent; interaction design; work space design; continuous robot surfaces; reconfigurable space.

ACM Classification Keywords
• Human-centered computing~Collaborative interaction
• Human-centered computing~User interface design
• Human-centered computing~User centered design
• Human-centered computing~Interaction design theory, concepts and paradigms

INTRODUCTION
In an increasingly digital society, we have witnessed many environments or installations which are intelligent and interactive. Famous examples include "HypoSurface" by MIT Media Lab [[1]] and "MuscleBody" by TU Delft Hyperbody Research Group [[2]]. Most of these interactive architectural installations focus on providing new and interesting interactions to the users without further discussing the essential questions such as why we would like to enable such interactions (theoretical foundations); what influences such an interactive environment would have on human users; how we should design such interactive environment effectively; and how to evaluate the interactive environment. The answers to these questions are important not only as the justifications of the project, but also the rationales through which new designs could be better informed and consequently, improved. Inspired by these questions, the authors decide to explore interactive environment design through the research and design of an "intelligent and interactive work environment for interior designers," which serves as the specific case to narrow down the scope of our research topic.

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SPACE AGENT
As computer-embedded systems become more interactive and more intelligent due to rapid development of computational technologies. Researchers of the 1990s conceptualized the research paradigm, CASA (Computer as Social Actors) [[3]]. As part of this conceptualization, Reeve and Nass proposed "The Media Equation" as a general communication theory that describes the tendency of people to interact and communicate with computer media as if this media is a human being [[4]]. Since then, many psychological experiments studying human communications have been conducted to inform human-computer interaction design [[5]]. Design researchers initially applied these psychological findings to virtual, avatar designs. More recently, design researchers have been transferring "common interpersonal communication phenomena" [[5],[4]] to computer-embedded systems such as robotic furniture [[6]] and social robots [[7]].

Herein, the authors suggest that a computer-embedded intelligent space, such as an intelligent work space, may also be perceived by users as a human being—partner, friend, collaborator, which is the definition of "space agent." Consequently, studying human-human interaction may predict how people would like to communicate and interact with an intelligent space. This concept could greatly influence and richly inform how interactive and intelligent spaces are designed, and the interactions these spatial artifacts afford. We will further discuss the "space agent" concept and corresponding design pattern framework in the TEI 2019 conference presentation for our paper "Designing Interactive Spaces as if They Were Human: A Design Pattern Framework for the 3rd Dimension."

INTELLIGENT WORK SPACE AS A SPACE AGENT

What should an intelligent work space look like? In Figure 1, below, we list four different spaces with different intelligence levels and interaction patterns.

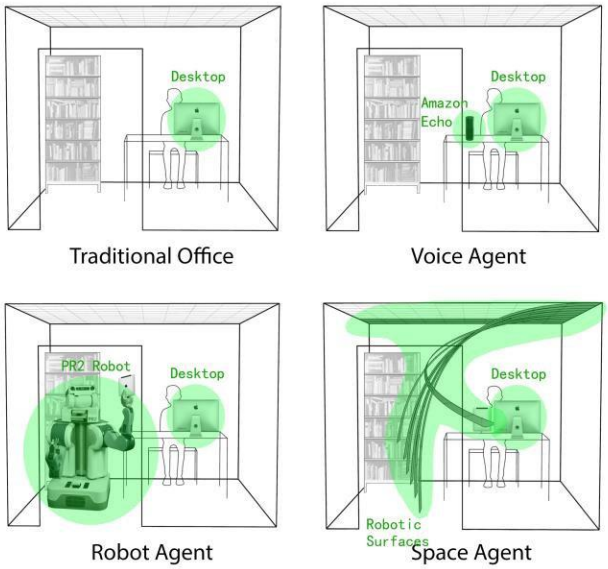

Figure 1. Diagram of four different work spaces: traditional office, voice agent, robot agent, and space agent.

The first one is our everyday office with a chair, a desk, a desktop computer, and hopefully a bookshelf. There is no intelligence or interactions in the space. Recently, people start to have an "Amazon Echo" or "Google Home" on their desks. These "Voice Agents" could perform some simple tasks with users such as turning on the light or TV, which gives certain level of intelligence and verbal interactions to the work space. Or, we could have a "Robot Agent" in the room. A well programmed PR2 robot, as shown in Figure 1, could do some simple tasks with certain level of intelligence and support some verbal and non-verbal interactions. Finally, we have the option of designing the work space as a "space agent," which could proactively reconfigure the physical work space to support different activities as if a partner to the users. It gives user the ability to control physical space configurations, while at the same time manifests intelligent partnership by perceiving what users are doing and being supportive. In Figure 1, the "Space Agents" are designed as robot surfaces peeling off the ceiling, which divides the work space into two parts.

A STORY OF JOANNE

Now let's look at how "Space Agent" could partner with our persona "Joanne," an interior designer, in her various design activities in the following scenario. The sentences in *italic font* below are descriptions of sub-tasks performed by the "space agent."

Figure 2. Robotic surfaces as a space agent applied in autonomous car interior: meeting clients.

Figure 3. Robotic surfaces as a space agent applied in autonomous car interior: private working.

Joanne is an interior designer. Her office is an intelligent work space with robotic surfaces attached to the ceiling, capable of reconfiguring and redefining the interior space. Today, Joanne needs to design a chair for her clients. She steps into the office in the morning and sits beside her desk. *One of the robotic surfaces embedded in the ceiling gently bent down to provide her a tablet in a comfortable position (see Figure 2).* After checking her email on the tablet, Joanne keeps staring at computer screens and still doesn't feel in the mood of creating new chair designs for her clients from Switzerland. *The robotic surface with the tablet tentatively moves into Joanne's eye sight with two words on the screen: "need inspirations?"* Joanne nods her head slowly. *The screen then suggests: "site environment simulation" and the robotic surfaces start to create the feeling of "cold winter in Switzerland" using lights, movements, and sounds.* Joanne feels the atmosphere and starts to sketch on the paper. Suddenly, her calendar reminds her that an online conference with her clients is happening in 10 minutes. *Joanne quickly picks up her old and new sketches while some robotic surfaces start to bend down together forming a pin-up wall surface beside Joanne*, so that she could pin her drawings in an organized way for her clients. Meanwhile, her colleagues are coming into the office. *Some other robotic surfaces gently bent down to separate Joanne and her colleagues spatially and block the noise (Figure 3).* After some time, Joanne feels tired and wants to have a rest. She stands up and leans

towards a soft robotic surface on the wall. *The soft robotic surface changes its surface curvature in a way providing both ergonomic and comfortable body support for her leaning gesture.*

SPACE AGENT AS A DESIGN PARTNER

In the scenario above, we see how the space agent (robotic surfaces) could detect user activities and proactively reconfigure the interior space to support design activities. We believe that the more "Joanne" working with the space agent, the more space agent could understand her behavior patterns and become her design partners. Why do we believe "space agent" could become a design partner? What does this partnership mean to the designers? What influences could "space agent" environment have to the users? And finally, what are the previous examples I could build upon? In this section, we reviewed some literatures to give meaningful answers to these questions.

Three Key Characteristics of a Good Partner

Bratman (1992) proposed the "Trio of features characteristic of SCA" which are "mutual responsiveness," "commitment to joint activity," and "commitment to mutual support" [[8]]. Based on the current AI technology, space agent could perceive what users are doing well enough to infer the goal of the current task. Meanwhile, "space agent" is trying to be supportive to the users by being responsive to user's non-verbal behaviors. These characteristics qualifies a "partner" in a "Share Cooperative Activity." However, because of the time limit of my dissertation, I would only expect a "temporary partnership" between "space agent" and participants in the performance experiment.

Space Agent – Spatial Support – Creativity

Space Agent is a reconfigurable space that is not only proactive to user behaviors, but also under control of users. For instance, if certain reconfiguration is not favored by the users, the users could gesture the room to return to the previous configuration. The proactive part of space agent is conveying the idea of being supportive. McCoy and Evans suggest that environmental supports (both social and physical) are salient to creativity [[9]]. Amabile and his colleagues have studied how social environment could influence creativity [[10]]. As McCoy and Evans suggest that "just as the social environment provides support, the physical environment may reflect and reinforce that support." [[9]] In summary, the literatures support the following rationale: Space Agent may proactively provide spatial supports which could be salient to creativity.

Space Agent – Control over Space – Work Environment Satisfaction

Previous studies suggest that staying in control over the space could allow workers to better focus on their jobs [[11]]. For instance, the space agent could provide privacy and block noises. The control over space, together with the active spatial support provided by the space agent, could potentially improve the work environment satisfaction of the users, which could further contribute to many other things such as working efficiency and creativity [[11]]. Luck in his Ph.D. dissertation also suggests that "locus of control" and "perceived control" could positively influence "workplace preferences" and "job satisfaction" [[12]].

Space Agent – Partnership (Friendship) – Creativity

James Somers, in his recent New Yorker magazine article, specifically described how partnership and friendship become a power horse of creativity at Google [[13]]. Good partners complement each other in a dynamic way, cultivating a good relationship (friendship) which in return positively influence the complementary partnership. Michael in her book argues that creativity is born from collaborations and the friendship among the collaborators [[14]]. She used examples and related studies to support this argument in her book.

Previous Example

I would like to position my dissertation topic in the domain of "architectural robotics", which is a sub-field of interactive architecture. "Architectural robotics" is described as an "interactive, partly intelligent, and meticulously designed physical environment." [[15]] One "architectural robotics" example closely related to my dissertation project is "Animated Work Environment" (AWE), which is a reconfigurable work station consist of a one-dimensional bending structure [[16]]. Compared to "AWE," "space agent" expand the reconfigurable space scale to the whole office and emphasis specifically on the interactions and relationships between the space and users.

TECHNICAL BOUNDARIES

Specifically, we need supervised learning and classification algorithms operating with large enough database and fast enough computational speed. We have already developed the prototype of this technology using MATLAB for model training and grasshopper for implementation [[17]]. However, to achieve a proper space agent behavior, we should integrate cost-based prediction functions [[18]] or HMM smoothing, filtering, and prediction [[19]]. Further explorations in AI algorithms are still needed to achieve proper partnership interactions between "space agent" and designers.

RESEARCH QUESTIONS AND RESEARCH DESIGN

Based on the concept of "Space Agent" and literature reviews above, we have the following research questions:

- How to design the interactions between "Space Agent" and human user, so that it can develop a temporary partnership with human designer?
- Could the "space agent environment" and the "temporary partnership" together, increase designers' "work environment satisfaction" and "creative work performance?"

For the first research questions, we propose three different interaction patterns to be explored in the pilot study, which will be further explained in the "experiment design" section:

- *Interaction pattern 1*: users need to push a button to enable certain space reconfiguration;
- *Interaction pattern 2*: space agent always asks for permissions before it actively reconfigures the space;
- *Interaction pattern 3*: space agent proactively reconfigures the space without asking for permissions but will return to its former configuration when users gesture it to stop.

For the second research question, we plan to explore it in the "performance experiment." The research design for this research question is illustrated in Figure 4.

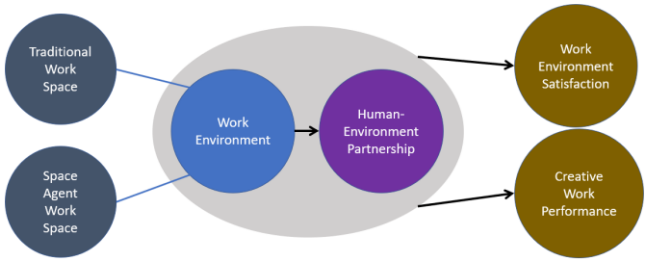

Figure 4. Research design diagram

As shown in Figure 4, the independent variable is work environment, which is a categorical variable with two levels: "Traditional Work Space" and "Space Agent Work Space." We believe the "space agent work space" could develop a temporary partnership with its users by providing proactive spatial support based on its understanding to the human activities. Meanwhile, the human users will experience his control over the work space in this partnership. The dependent variables are "work environment satisfaction" and "creative work performance." These two variables are based upon previous literature reviews and can be measured by existed scales.

EXPERIMENT DESIGN

Experiment-1: Pilot Study of Interaction Patterns and Spatial Configurations for Each Sub-task

In this pilot study, we'll invite 12 interior designers to go through the exact scenario we described in the "story of Joanne," by performing the same design task (design a chair) inside a space agent environment. we're going to ask participants to co-design with us the spatial configuration for each sub-task (the sub-tasks are specified in the scenario using italic font). Then We'll use VOZ technique to simulate three different interaction patterns (specified in "research question and research design" section) for each sub-task and ask participants which one they prefer and why. Table 1 shows five sub-tasks and corresponding interaction patterns we will explore in this pilot study.

Experiment-2: Performance Studies

In our performance studies, 22 participants will be asked to perform tasks based on the scenarios. We will: (a) measure how robot surfaces facilitate a human participant performing specific tasks; and (b) observe, measure, and characterize human-robot activity patterns and processes. Quantitative methods will be used to measure proposed variables. For "creative work performance," we will organize a design expert panel to evaluate the outcome of performed tasks such as the quality and quantity of design works or ideas generated by the participants. For "work environment satisfaction," we will give participants a validated scale after they performed the required tasks in the "space agent" work space. Qualitative methods used in the performance studies are the same as those used for the usability and user experience studies: a mix of observations, interviews, think alouds, surveys, and coded video-recording of sessions. Analysis of these data will be a key factor in informing the team members of the absolute and relative merits of the surface robot designs.

Sub-tasks	Interaction pattern 1	Interaction pattern 2	Interaction pattern 3
Providing tablet for email checking	Push a button, then tablet is provided by a robotic surface	SA asks for permission first, then provides the tablet	SA provides the tablet without asking for permission
Simulating site environment	Push a button, then SA starts to simulate site environment	SA asks for permission first, then simulates site environment	SA simulates site environment without asking for permission
Forming a pin-up wall	Push a button, then pin-up wall is provided in the right position	SA asks for permission first, then starts to form pin-up wall	SA forms the pin-up wall without asking for permission
Spatially separating users into different groups	Push a button, then robotic surfaces come down to separate different user groups	SA asks for permission first, then form the partitions	SA forms separating partitions without asking for permission
Providing comfortable surfaces for leaning gestures	Push a button, then robotic surfaces change curvatures to support leaning gesture	SA asks for permission first, then provides the leaning surface	SA provides leaning surfaces without asking for permission

Table 1. Three interaction patterns for five sub-tasks ("SA" represents "Space Agent")

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