Spatial User Interaction: What Next?

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Keywords: Spatial User Interaction, Interaction Design, Framework, Smart Environments, Ambient Intelligence.

Abstract: Spatial user interaction refers to interactions that use spatial attributes or spatial relations between entities to trigger system functions. Spatial user interaction can offer intuitive interactions between users and their environment, particularly in ubiquitous environments where interconnected objects are in constant interaction. Many research works demonstrated the relevance of the spatial user interaction paradigm. Nevertheless, only a few were conducted to standardize the necessary concepts for designing spatial applications and to propose software tools that support spatial user interaction. The present work reviews the literature for spatial user interaction design and development. It analyses papers dealing with applications supporting spatial user interaction. It shows a lack of generic tools for designing/developing applications supporting spatial user interactions and proposes directions for future research work in this field.

1 INTRODUCTION

Nowadays, IT (Information Technology) goes beyond the boundaries of professional areas to dominate our daily activities. This implies the use of technology by a variety of users with different skills, preferences and ages. Human computer interaction models passed from textual (Command-Line Interface) and graphical (WIMP[1]) to natural (post WIMP) ones. This remarkable evolution is need-oriented per more natural and intuitive relation between machine and user.

Ubiquitous computing consists of multiple interconnected input and output devices, often embedded in daily used physical objects which cooperate seamlessly and can be combined together to help users accomplish daily tasks. Ubiquitous computing brought new research approaches, like tangible user interfaces (Ishii and Ullmer, 1997), which focuses on using physical objects as input (and sometimes output) devices. More recently, researchers aim to design ambient environments featured with multiple sensor technologies, such as interactive media arts (Aylward and Paradiso, 2006) (Tanaka and Gemeinboeck, 2006), interactive workspaces (Bongers and Mery, 2007). But recent technologies like smartphones, flat displays and some kind of input devices (RFID[2], NFC[3]) and networks (Wifi, Bluetooth) made deeper exploration possible (Huot, 2013). In such environments, the concept of spatial user interaction becomes really interesting.

Spatial user interaction refers to interactions that result from considering spatial attributes of etities or spatial relations between them to trigger system functions. Many works (academic and marketed) have been proposed. They demonstrated the relevance of the spatial user interaction paradigm. For example, the *Teletact* device (Bellik and Farcy, 2002) is a triangulating laser telemeter adapted to the space perception for the blind. The blind user receives different sound feedbacks depending on the distance of the obstacle detected by the device. Figure 1 is a photography of the *Teletact* mounted on a white cane.

We present in this paper a literature review around spatial user interaction design and development. As we will show later, there is a lack of tools and methods that help designing applications supporting spatial user interactions.

The outline of this article is as follows. Section 2 focuses on the spatial user interaction paradigm. Section 3 presents a taxonomy of existing interac-

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[1] Windows, icons, menus, pointer

[2] Radio Frequency IDentification

[3] Near Field Communication

Chaoui, K., Bouzidi-Hassini, S. and Bellik, Y.
Spatial User Interaction: What Next?.
DOI: 10.5220/0010836700003124
In *Proceedings of the 17th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2022) - Volume 2: HUCAPP*, pages 163-170
ISBN: 978-989-758-555-5; ISSN: 2184-4321

Figure 1: *Teletact* mounted on a white cane (Bellik and Farcy, 2002).

tion models in order to position spatial user interaction among them. Then, section 4 provides a state of the art on spatial user interaction and section 5 provides a discussion. Finally, we provide conclusions and perspectives of this work.

2 SPATIAL USER INTERACTION

There is not yet a consensus on the definition of the concept of spatial user interaction. This is why we propose the following one: "*Spatial user interaction refers to interactions that result from considering spatial attributes or spatial relations between entities to trigger system functions*" (Chaoui et al., 2020).

Spatial user interaction can be *implicit* or *explicit* depending on the user's intention. If the user intentionally acts in order to trigger a certain system function then the interaction is said to be *explicit*. On the contrary, if the system's function is triggered without the user's intention, then the interaction is said to be *implicit*. Note that explicit interactions can be performed by using input interaction devices or sensors, but implicit interactions are performed only with sensors.

Proxemic interaction represents a particular research topic of spatial user interaction. System functions are triggered according to the proxemic relationships between users and devices. Four variables are defined to serve for building and interpreting the interaction between people and a system within the ecology of devices (Greenberg et al., 2011):

- *Distance*: determines the level of engagement between user and the system devices.
- *Orientation*: provides information about which direction an entity is facing with respect to another.
- *Location*: indicates the location of the entity.
- *Identity*: knowledge about the identity of a person, or a particular device.

Proximic and spatial user interactions may appear similar, but actually they are not. The main difference between them is that distance is the main spatial attribute used in proxemic interactions as it defines the level of attachment between user and the surrounding devices of the system which is not the case in spatial user interactions. Consequently, spatial user interaction is more general than proximic one as it defines interactions by considering various spatial attributes and relations that may be different from distance such as speed, acceleration, weight, etc. Furthermore, spatial user interaction aims to exploit orientation and location in a richer way than proxemic interaction does.

3 TAXONOMY OF INTERACTION MODELS

In order to position spatial user interaction with respect to existing other interaction models, we examined proposed interaction model classifications in the litterature. (Kim and Maher, 2005) distinguishes *digital* and*physical* interaction models and presents a comparison study of two collaborative systems (workbenches) designed according to both models. The digital model is implemented by a graphical interface and the physical one is illustrated by a tangible interface. According to the authors, physical interaction refers to any interaction that uses a physical object for invoking a system's function. It refers also to any technique applied in the physical space and which uses physical objects to interact. We think that classifying models into digital and physical ones is an interesting idea. However, such classification does not cover all existing models. For example, speech interaction is not digital, nor physical (in the sense of motor activity). So, if we adopt this classification, we cannot place speech interaction anywhere.

Authors in (Grosse-Puppendahl et al., 2017), propose a taxonomy to classify capacitive sensing approaches based on various criteria, such as sensing goal, instrumentation of objects into the interaction etc. Therefore, if we look closely to this classification we notice that interactions are actually Sensor-Based.

We think that it is important to precise the difference between the concepts of *sensors* and *input devices*. We consider that input devices are provided with a set of predefined events (such as mouse click, mouse double click, mouse move, keyboard key press, keyboard key release, etc.) which describe how to use the device. The designer/developer can use these events to implement his application. Events then serve as building blocks (or alphabet) for the considered interaction language. On the other hand, Sensors produce information on the state of a given entity (temperature, brightness, location, speed, etc.). This information can be produced permanently (at a given frequency) to the developer or as a response after a request. Note that an input device can also provide information on its state, but this is generally done only at the request of the developer and not permanently.

Defining a classification of interaction models is not an easy task, as models evolve and new ones emerge from time to time. To have a solid classification, we prefer to define general questions that allow each model to be positioned according to the answers provided. We list three general questions: (1) Where does the interaction take place? (2) What means are used to perform the interaction? (3) What is the complexity level of the interaction language structure? We explain these items in the following paragraphs and we summarize answers to these questions according to most used interaction models in Table 1.

Q1: Where Does the Interaction Take Place?
Here we mean where the manipulation of the target objects of interaction takes place: they can be in the digital world (graphical and touch interactions), in the real world (tangible, spatial user interactions), or in both worlds (mixed reality).

Q2: What Means Are Used to Perform the Interaction?
The means used to perform the interaction can be the user's body or parts of it (hands and facial expressions for sign language, vocal cords for speech, user's position for spatial user interaction), physical objects (such as in tangible or spatial user interaction), interaction devices (mouse and keyboard in GUI), sensors (ambient and spatial user interaction), or a combination of several of these means.

Q3: What Is the Level of Complexity of the Interaction Language?
The complexity of the used interaction language may vary from a low to a very high level . Some interaction languages are based on a small set of events (graphical, spatial, and tangible models), while others use a certain number of commands (shell language). We may also find some languages with simple grammar (voice commands) and some languages with more complex grammar (natural language, sign language, etc.).

We thus conclude that several parameters should be considered to distinguish interaction models. These parameters must be technology independent because interaction models are constantly evolving. In our work, we propose three parameters: the place, the means and the interaction language. According to Table 1, we can see that spatial user interaction is a *real-world interaction*, *object-based* or *body-based* and uses *event–based language*.

4 STATE OF THE ART

We present in this section a literature review for applications supporting spatial user interaction and tools for spatial interface development.

4.1 Applications Supporting Spatial User Interaction

To analyze existing works on spatial user interaction, we carried out a targeted study broken down into two main stages: (i) research of works relating to spatial user interaction (ii) analysis and classification of these works according to spatial properties used to support spatial user interaction. Table 2 summarizes works that we analyzed from the literature and classify them according to 3 spatial properties used by these works: Location, Orientation and Distance. Figure 2 shows the percentage of the analyzed systems that use each spatial property or combination of them. For instance, we found that 68% of the analyzed systems use Location.

4.1.1 Location

Location represents object coordinates in the physical space, usually in the 3D space (x, y, z). Different applications use this information to implement spatial interaction between the user and the system. In the *Follow-Me system* (Addlesee et al., 2001), the user moves around a given place while the system tracks his location and the interface of the application follows her/him allowing her/him to use the nearest appropriate input device. *Proximo* (Parle and Quigley, 2006) is a location-sensitive mobile application that helps users to keep track of different objects using Bluetooth technology. *The curb* (Bruner, 2012) was initially an application for retrieving building information and evolved into a registration mobile application that allows users to control access to their rooms. *SpaceTop* (Lee et al., 2013) allows users to type, click, draw in 2D and directly manipulate interface elements that float in the 3D space above the keyboard. In *Spatially-Aware Tangibles Using Mouse Sensors* (Schüsselbauer et al., 2018) the authors demonstrate a simple technique that allows tangible objects to track

Table 1: Answers to the classification questions according to most used interaction models.

	Interaction Models						
	Command-Line Interface	**Graphical User Interface**	**Speech interaction**	**Gesture interaction**	**Touch interaction**	**Tangible interaction**	**Spatial User Interaction**
Q1	Digital world	Digital world	Digital or real world	Digital or real world	Digital world	Real world	Real world
Q2	Device (keyboard)	Devices (mouse, keyboard)	User's body (vocal cords)	User's body (hands, facial expressions)	Device (touch screen)	Physical objects	User's body, physical objects or a combination of them
Q3	Commands	Events	Grammar	Events, Grammar (sign language)	Events	Events	Events

their own position on a surface using an off-the-shelf optical mouse sensor.

4.1.2 Orientation

Orientation determines the information about which direction an object is facing another one. *HOBS* (Zhang et al., 2014) is an application that uses a selection technique based on the orientation of the head to interact with smart objects in physical space remotely. Note that the orientation attribute is generally used with the position attribute, it is rarely considered lonely in a system.

4.1.3 Distance

Distance represents the amount of space that separates two objects. It is often referred to by the term "proximity". Spatial interactions based on distance do not depend on specific locations but rather on the space between these locations. This is particularly true in the case of two mobile entities. For instance, *ConnecTable* (Tandler et al., 2001) is a system that allows two screens to be coupled together when they are close to form a single screen, whatever their precise locations are. *Pirates!* (Falk et al., 2001) is a multiplayer computer game which runs on handheld computers connected using wireless LAN. The virtual game environment is maintained and controlled by a local server which also keeps track of the players' progress over time. *The Hello Wall* (Prante et al., 2003) is a public display system that presents information of general interest when no one is in the immediate closeness and provides more personal information when a user is in close proximity. *Proximate Interactions* (Rekimoto et al., 2003) is a wall-sized ambient display supporting three different zones of interaction, which are user distance dependent. *Mirror Space* (Roussel et al., 2004) is a multi-user interactive communication system that depends on distance. It creates a continuum of space for interpreting interpersonal relationships. *Novest* (Ishikawa et al., 2017) is an interface used to estimate the location of the finger and to classify its state using the back of a hand.

4.1.4 Location and Orientation

Some applications combine location and orientation information to implement spatial interactions. *Virtual shelves* (Li et al., 2009) is an interface that allows users to execute commands by spatially accessing predefined locations in the air. *Pure Land AR* (Land Augmented Reality Edition) (Chan et al., 2013) is an installation that allows users to visit virtually the UNESCO World Heritage-listed Mogao Caves. *Interactive Lighting* (Hakulinen et al., 2013) is a multi-level software framework that allows the creation of user interfaces to control lighting. *Slab* (Rateau et al., 2014) is an interactive tablet for exploring 3D medical images. *Jaguar* (Zhang et al., 2018) is a mobile AR system with flexible object tracking for context awareness.

4.1.5 Location, Orientation and Distance

We also found applications that combine location, orientation and distance: *iCam* (Patel et al., 2006) is a handheld device that can accurately locate its position and determine its absolute orientation when it is indoors. It can also determine the 3D position of any object with its onboard laser pointer. *Mobile spatial interaction* (Holzmann, 2011) is a method of estimating the distance and location of arbitrary objects in the view field of a mobile phone. This approach uses stereo vision to estimate the distance to nearby objects, as well as GPS and a digital compass to get its absolute position and orientation. (Jakobsen et al., 2013) presented a study where they explore how to use the proxemic variables among people to drive interaction with information visualizations. *Kubit* (Looker and Garvey, 2016) is a responsive holographic user interface using proxemic interaction. (Huo et al., 2018) is a method that enables spatial context-sensitive interactions, instant discovery and localization of surrounding smart things. (Garcia-Macias et al., 2019) is a proxemic system intended to help the visually impaired to move around physical spaces.

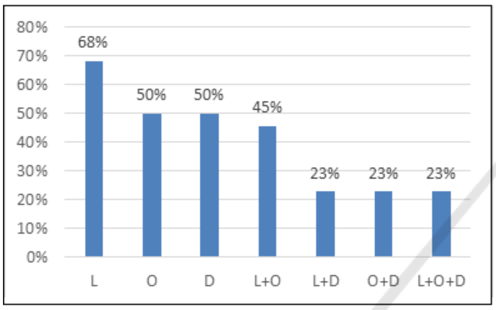

Figure 2: Use of spatial properties in the studied systems (L: Location, O: Orientation, D: Distance).

4.2 Tools for Spatial Interface Development

Usually, user interface design tools refer to methods, languages, or software used for interface design. They can significantly facilitate the expression of design ideas. In order to analyze works on tools that support the design and implementation of spatial user interactions, we made a focused study broken down into two main stages: (i) research of works related to the design/development of spatial applications, (ii) setting up a comparative table based on two criteria: Tool type and Genericity.

Different design tools exist for graphical (Vos et al., 2018), touch (Khandkar and Maurer, 2010) and multimodal interfaces (Elouali et al., 2014). However, concerning spatial user interaction design and development, there is no attempt to propose tools that might help designers in their task. Despite the existence of a few tools for proxemic interactions which represent a particular point of view of spatial user interaction, where distance plays a fundamental role, they remain intended for very specific applications.

Table 3 summarizes works related to designing tools that we describe below.

Table 2: Applications supporting spatial user interaction according to considered spatial properties.

Reference	**Spatial properties used**		
	Location	Orientation	Distance
(Addlesee et al., 2001)	X		
(Parle and Quigley, 2006)	X		
(Bruner, 2012)	X		
(Lee et al., 2013)	X		
(Schüsselbauer et al., 2018)	X		
(Zhang et al., 2014)		X	
(Tandler et al., 2001)			X
(Falk et al., 2001)			X
(Prante et al., 2003)			X
(Rekimoto et al., 2003)			X
(Roussel et al., 2004)			X
(Ishikawa et al., 2017)			X
(Li et al., 2009)	X	X	
(Chan et al., 2013)	X	X	
(Hakulinen et al., 2013)	X	X	
(Rateau et al., 2014)	X	X	
(Zhang et al., 2018)	X	X	
(Patel et al., 2006)	X	X	X
(Holzmann, 2011)	X	X	X
(Jakobsen et al., 2013)	X	X	X
(Looker and Garvey, 2016)	X	X	X
(Huo et al., 2018)	X	X	X
(Garcia-Macias et al., 2019)	X	X	X

(Perez et al., 2020) proposed a proxemic interaction modeling tool based on a DSL (Domain Specific Language). The latter is composed of symbols and formal notations representing proxemic environment concepts which are: *Entity*, *Cyber Physical System*, *Identity, Proxemic Zone*, *Proxemic Environment* and *Action*. From a graphical model, the tool creates an XML schema used to generate executable code. In (Marquardt et al., 2011) the authors presented a proximity toolkit that enables prototyping proxemic interaction. It consists of a collection library conceived in a component-oriented architecture and considers the proxemic variables between people, objects, and devices. The toolkit involves four main components: (1)*Proximity Toolkit server*, (2) *Tracking plugin modules*, (3)*Visual monitoring tool* and (4) *Application programming interface*. A proxemic designers' tool for prototyping ubicomp space with proxemic interactions is presented in (Kim et al., 2016). It is built using software and modeling materials, such as: photoshop, paper and Lego. Interactions can be defined in photoshop based on proxemic variables. The tool uses an augmented reality projection for miniatures to enable tangible interactions and dynamic representations. A hidden marker stickers and a camera-projector system enable the unobtrusive integration of digital images on the physical miniature. SpiderEyes (Dostal et al., 2014) is a system and toolkit for designing attention and proximity aware collaborative scenarios around large wall-sized displays using information visualization pipeline that can be extended to incorporate proxemic interactions. Authors in (Chulpongsatorn et al., 2020) explored a design for information visualization based on distance. It describes three properties (boundedness, connectedness and cardinality) and five design patterns (subdivision, particalization, peculiarization, multiplication and nesting) that might be considered in design.

Table 3: Summary of designing tools for proximic user interaction.

Reference	Tool type	Genericity
(Perez et al., 2020)	Modeling language and prototyping environment	Generic
(Marquardt et al., 2011)	Prototyping environment	For specific use
(Kim et al., 2016)	Prototyping environment	For specific use
(Dostal et al., 2014)	Prototyping environment	For specific use
(Chulpongsatorn et al., 2020)	Prototyping environment	For specific use

5 DISCUSSION

The purpose of this study was to analyze works related to spatial user interaction design and development. Currently, there are a lack of tools and methods that help designing applications supporting spatial user interactions. Accordingly, a literature review around spatial user interaction design and development could contribute to the body of knowledge of spatial user interaction design and development.

In the following we provide some discussions about our review results.

5.1 Spatial User Interaction Design Gaps

According to the literature review, most of the proposed works aim to demonstrate the relevance of the spatial user interaction technique in itself rather than on how to specify it in a generic approach and reusable way. Hence, there is a lack of generic approaches and tools capable of handling the process of building applications supporting spatial user interaction. Furthermore, existing works do not take into account all the possibilities of spatial interaction. It treats only proxemic interactions which are mainly based on distance. Moreover, proposed tools target the prototyping of specific applications, except the recent research of (Perez et al., 2020) which came forward to define a language for proxemic interaction specification.

5.2 Spatial User Interaction Design Next Step

For future work, we think that it will be necessary to define a modeling language for spatial user interaction. On the one hand, it allows specifying what concepts to use, in which case and how to specify different interactions. In this way, designers/developers could easily refer to them when building applications supporting spatial user interaction. On the other hand, richer spatial user interactions should be more systematically exploited by designers through the spatial user interaction modeling language. Furthermore, it helps to develop a modeling and code generation frameworks for the automation of parts of development.

6 CONCLUSIONS

Spatial user interaction promotes intuitive and simple exchanges between users and the system. The purpose of the present paper is to present a literature review and an analysis relevant to this topic.

In order to position the spatial user interaction model among the existing ones, we proposed a classification that takes into account three parameters: *interaction place*, *interaction means* and *interaction language*.

Next, we presented a literature review on existing spatial applications and design tools. Based on the review results, we identify a lack of generic approaches and tools capable of supporting the process of building applications with spatial capabilities. Few interest was given to the way spatial user interactions are designed, despite the fact that many works have proven the usefulness of spatial user interaction as it offers natural and intuitive exchanges between users and systems. Several applications that support spatial user interaction exist exploiting thereby some spatial attributes.

In order to respond to the shortcomings pointed out in the literature, currently we work on proposing a modeling langage for spatial intercations.

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