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Design and evaluation of distributed user interfaces between tangible tabletops

Amira Bouabid · Sophie Lepreux · Christophe Kolski

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Abstract The advantage of tangible interaction is that it allows people to interact naturally. Tabletops are a collective support which can be used by several people simultaneously. In previous work, tabletop and tangible interaction were shown to be of interest in the learning process; the previous application was based on a classification task helping very young children in the recognition and learning of colors on one tabletop. This paper concerns distribution between connected tabletops. In order to provide a supervision tool in our case, this paper proposes more generally to distribute user interfaces between interactive tabletops which use tangible interaction. A design model is proposed for this type of system and is applied to design a distributed application for children and a supervisor on two interactive tabletops. An evaluation, with twelve test groups, each composed of three participants, has involved a distributed application for the learning and recognition of colors. This study is supported by observations, trace analysis and questionnaires. In the study, we analyze if design choices, guided by the model and providing generic objects, allow the users to interact remotely, easily and understandably. The user satisfaction when using the distributed tangible tabletops, is also studied. After the discussion, a conclusion and future works are proposed.

Keywords distributed UI · remote collaboration · RFID · Interactive tabletop · tangible object · tangiget

1 Introduction

Computers are being used in schools with increasing frequency. Today, there are not only calculators in the classrooms; lots of interactive whiteboards, tablets and robots are integrated in the school teaching material. In France, for example, certain schools known as “smart schools” have been providing education with a computer for each child [45]. For several years now, the same approach has been observed in many European countries, the United States and other countries [20, 23, 30].

The interest in using tables in education (in a general way) is not new. For example, the work of Thomson et al. [61], Ampofo et al. [2] and Fyhri et al. [16] has shown that the table (a standard table though not an interactive tabletop) is a good way to recreate the real environment and expose children to interesting traffic situations; Fyhri et al. use the table concept (e.g. a model with objects representing road traffic) to raise children’s awareness of road traffic problems.

Since the development of the first tabletops, research works have shown that this type of platform is adequate to share interaction between several people [47]. Large screens allow several people to be around the tabletop [48, 44]. The application can be collaborative or not. In many cases, team members often need to exchange ideas [52], work on common tasks [54] or be informed about the progress of a task [70]. Some work has been done on the subject concerning the flow of information between users and platforms, see for instance [8].

The pedagogical values of object manipulation have

Amira Bouabid
LAMIH-UMR CNRS 8201, University of Valenciennes,
France
SETIT, University of Sfax, Tunisia
E-mail: firstname.name@univ-valenciennes.fr

Sophie Lepreux and Christophe Kolski
LAMIH-UMR CNRS 8201, University of Valenciennes,
France
E-mail: firstname.name@univ-valenciennes.fr

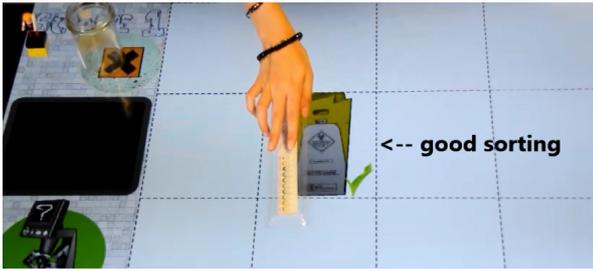


Fig. 1 A serious game dedicated to microbiological wasting

been promoted by Montessori [10]: “Children build their mental image of the world, through the action and motor responses; and, with physical handling, they become conscious of reality”. In addition, research has shown the interest of handling and using objects when applied to children’s education [1]. In their comparative study between GUI and TUI, Sylla and colleagues concluded that the tangible interface was capable of promoting a stronger and longer-lasting involvement having a greater potential to engage children [59]. Typically, tabletop technology usually proposes a tactile interaction. We focus in this paper on tangible interaction which allows the user to interact with physical (tangible) objects. Several authors have explained the basic principles linking tabletop and tangible interaction, see for instance [28,67,39]. One advantage of tangible interaction is that physical objects can be kept on the tabletops, contrary to fingers which cannot remain in the same place over a long period. Keeping the position makes it possible in a certain manner to maintain information on the tabletop. For instance, in [22] the interactive tabletop is used to play with microbiological materials in order to learn the wasting of contaminated products which must be handled and recycled as shown in Figure 1. In another domain [31], the tabletop is used to simulate road traffic. In this case, the vehicles are virtual and the road signs are tangible, Figure 2. Tangibility is, for instance, particularly interesting for a classification task: groups of tangible objects can be easily located on the tabletop (whether already placed in adapted zones or not) and then manipulated if necessary; the correct and incorrect placements can also be dated and recorded for later analysis. With tactile technology, it is not really possible to maintain a position for a long time. Other differences and advantages brought by tangible interaction are available in [4,25,26,56,39].

Our motivation in this paper is the following. In previous work, we demonstrate the advantages of using tangible interaction on interactive tabletops with tangible objects in an educative context [32,36]. The study was carried out with children in an ecological context,

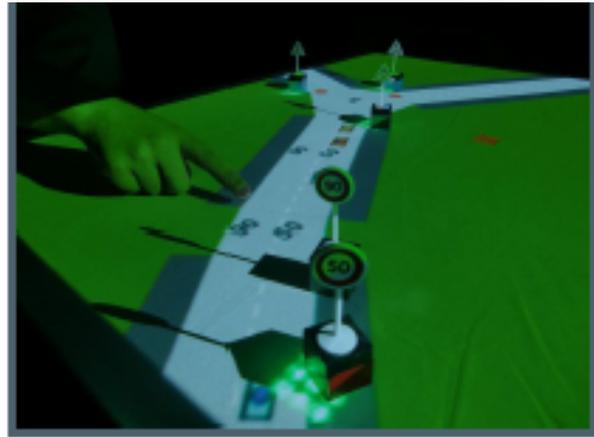


Fig. 2 A simulator of road traffic with tangible objects on interactive tabletop

in their classroom with their usual supervisor/teacher. The task used for the study was a simple classification task. In order to continue this research, the goal is now to provide one or several users (teachers, parents...) with the means to supervise and interact with a remote group of users, who are not necessarily children, performing a task via the interactive and connected tabletops. In this case, the user interface is distributed on the two connected tabletops. Such a distribution of a tangible application is a challenge because a tangible object on one tabletop cannot be tangible on another; such objects necessarily have a different and adapted representation and/or behavior on separate tabletops. The objective of this paper is to contribute to the design of distributed interaction between tabletops, in which the classification task on the first tabletop is supervised on the second one. This distribution can be useful to extend the display and the interaction surface. The distribution can also be remote to encourage exchange between non-located users. The paper focuses on this second configuration and extends work is presented in [6]. Section 1 proposes related work on design models dedicated firstly to tangible interaction and secondly to distributed user interfaces. In section 2, we propose a design model for distributed application on tabletops with tangible interaction that provides remote collaboration. Section 3 details how the model is used to design (or in our case to adapt) an existing application to be distributed. In this section we introduce some tangible objects, called tangigets, initially defined by Caelen and Perrot in [11] and Lepreux et al. in [41]. The evaluation is presented in section 4 in order to validate tangigets and distribution options. A discussion is proposed before concluding and proposing research perspectives.

2 Related Work on Design Models

This section includes two parts: (1) design models relative to tangible interaction and (2) design models dedicated to distributed interactive systems.

2.1 Design Models relative to Tangible Interaction

Different design models relative to tangible interaction have been progressively proposed in the literature. The most representative are resumed here.

Tangible User Interfaces (TUIs) differ from Graphical User Interfaces by a most important use of the perceptual haptic system. The items are not primarily graphic - and therefore perceptible only by sight but also, for some of them, perceptible in space by touching. Ullmer and Ishii differentiate these elements by giving them respectively the tangible and intangible denominations in their MCRit (Model-Control-Representation intangible and tangible) model; this model was called MCRpd (Model-Control-Representation physical and digital) [62] though the initial terminology has been modified in [64]. In addition, Ishii and Ullmer identified three different types of haptic feedback [27]; these have been modeled in [22].

In other works, Ullmer et al. [63] identified three types of TUIs: (1) Interactive Surfaces, (2) Constructive Assemblies (interconnections of modular physical elements), (3) Tokens + Constraints (Tokens are physical objects that represent digital information or operations; they are spatially reconfigurable). Fitzmaurice et al. propose the concept of graspable user interfaces [15]. A graspable object is composed of at least one physical artifact (called brick) associated with a virtual object. The bricks can be seen as input devices; they are tracked by the host computer which can capture the linked information and send/relay it to the application. Depending on the number of bricks used for an object and/or function, it is possible to define whether the interaction is unimanual or bimanual.

Holmquist et al. [24] determine a vocabulary to identify three different types of physical objects giving access to digital information and functions (stored outside the objects). These types of objects are: Containers, Tools and Tokens. These authors subsequently define a system they call Token-Based Access to Digital Information. This system is composed of (1) a set of physical objects, called tokens, representing digital information, (2) a set of interfaces, called information faucets, connecting the tokens to digital information.

Shaer et al. [57] propose the TAC (Token and Constraints) paradigm. It allows the analysis of the TUIs

via the possible relationships between physical and virtual elements. For this, Shaer et al. define different categories of items: (1) Pyfo (physical object that can be made of other physical objects), from the token or constraint category, (2) Variable (which represents digital information or computational function and can be coupled with a pyfo), (3) TAC (relationship between a token, variable and one or more constraints). Different rules are also defined for the categories of items. Since the first proposition by Ishii and his colleagues, different approaches have been proposed to model the elements implicated in tangible interaction: the TUI themselves and their associated components. These authors propose very important basic concepts for tangible interaction design. We can cite the separation between tangible (or physical) and intangible (or virtual or digital) information. However, the role of the object (tangible or virtual), the link with the task and the type of task (business task or functional task), is not clarified. Moreover, these models do not provide a concrete solution in the case of distributed tangible interaction.

2.2 Design Models dedicated to distributed interactive systems

In the context of multi-devices and user interface adaptation, many works [21, 43, 49, 55, 66] propose using model-based design to support Distributed User Interfaces. They distinguish adaptation (i.e. distribution) at design time vs. at runtime. In these works, the multi-devices correspond to cross-devices, i.e. there is only one UI at any given time; the change of context is characterized by a change of platform (device). We need, in this paper, distributed UI with eventually many UIs at a given time. For example in [53] the user interfaces are distributed across many devices co-located on a table and equipped with a lamp (which is the instrument that captures the device presence).

With the development of Ambient Environments, some works are focused on distribution in this context [42, 65]. In such environments, the UIDL (User Interfaces Description Language) has an important role. Luyten et al. [42] use UIML, whereas Vanderdonck et al. [65] base their works on the UsiXML project. In our context, the UI is managed by a Multi-Agent System using the XML language [37]. These works are thus compatible. In web development, mash-ups have been developed to support certain types of distribution [13]. With mobile applications, the distribution is performed between a set of mobile devices on a table. For example in [69, 68], a motion capture device and a coordination server make it possible to distribute information between a set

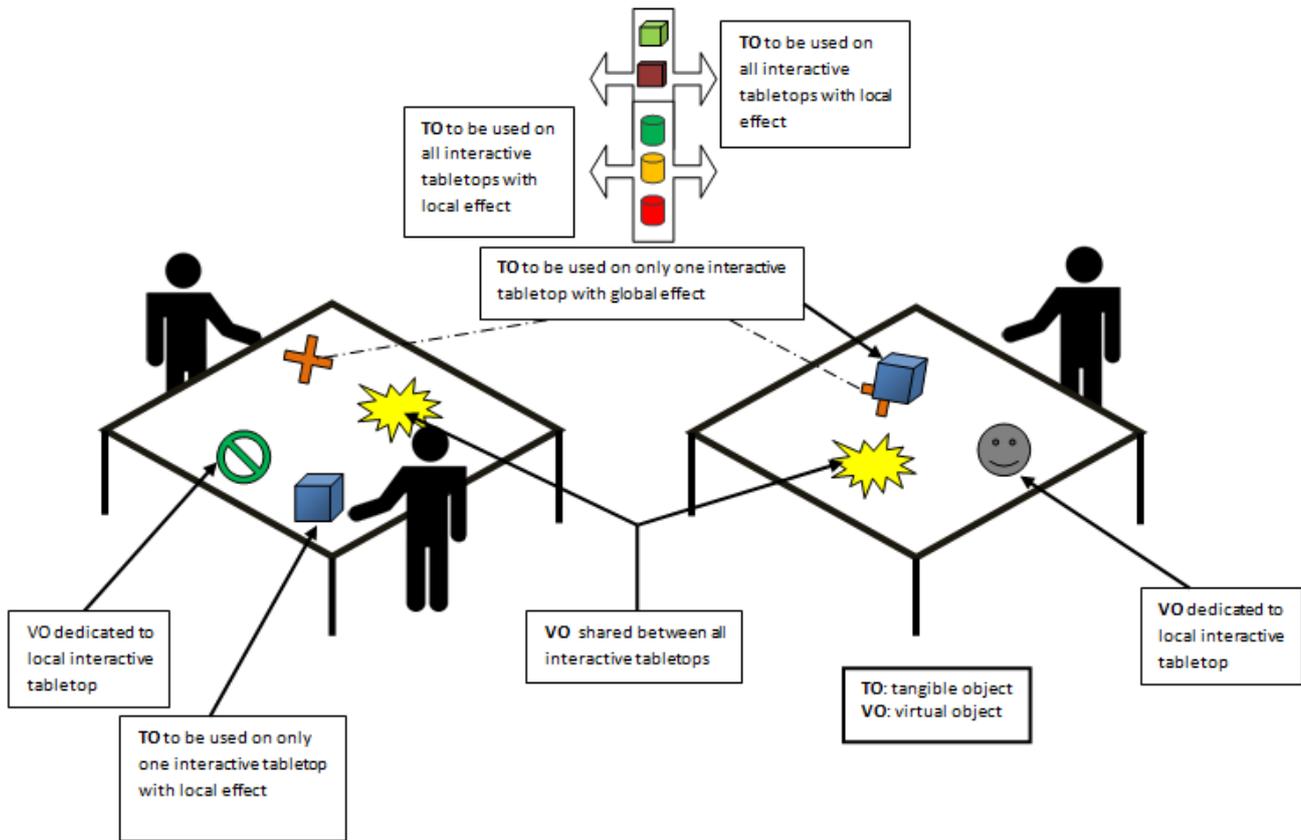


Fig. 3 An illustration of different design choices to distribute tangible interaction

of mobile devices each equipped with a dedicated mobile application.

In the distributed domain, the choice relative to privacy vs. the sharing of the information is crucial [50,29]. In our point of view, the choice has to be made according to the task(s) and the user(s); a task model including collaboration tasks is usable to make these design choices. Note that in [60] some discussions are relative to usability and collaboration in DUI. Among the guidelines to consider proposed by Penichet et al. [51], one issue is the distribution of shared and private workspaces to support balanced participation in face-to-face collaboration. This guideline needs however to be specified. Grolaux et al. [18] propose to characterize detachable User Interfaces with four properties: Detachability, Migratability, Plastifiability, Attachability. They suggest using these different choices in order to assemble or distribute UI Components of GUI applications. This definition is more general than the DUI that we consider. The definition proposed by Melchior [46] is closer to our view: “A Distributed User Interface (DUI) is defined as any application User Interface (UI) whose components can be distributed across different displays of

different computing platforms that are used by different users, whether they are working at the same place (co-located) or not (remote collaboration)”. In this work, Melchior proposes some distribution primitives which are based on the syntax defined through an Extended Backus Naur Form (EBNF) grammar.

Penichet et al. [51] prefer the definition provided by [14] in [17] where DUI was then described as a user interface whose components are distributed across one or more of the dimensions input [so called input redirection], output [so called display or content redirection], platform [i.e., architectures, operating systems, networks, etc.], space [i.e., co-located or remote interactive spaces], and time [synchronous or asynchronous].

Branton et al. [7] propose a framework named Ensemble. The Ensemble architecture is designed to encourage exploratory development by limiting the impact of changing components. The Ensemble architecture is comparatively lightweight, cross-platform, and capable of modeling a number of interaction styles and design patterns. They use Open Sound Control (OSC) messages to manage the communication between UI components.

Shmorgun et al. [58] propose to capitalize knowledge about DUI, in particular concerning design problems, in order to provide design patterns. This work is promising. The work presented in this paper could be integrated in such a research framework in the future.

Finally, some works deal with the DUI in the context of Tangible interaction on surfaces. De La Guia et al. [19] propose to couple tangible interaction, tablets and DUI. This work implies users with disabilities. The main difference between tablet and tabletop is privacy and the possible number of users around the surface. Kubicki et al. [34] show, through a model of context, the specificities of tabletops interacting with tangible objects, especially in a distributed context. Lepreux et al. [40] detail the tangiget concept proposed by [11] in order to equip tabletops with generic objects which are usable in different applications. Various concepts, properties and frameworks have been proposed, though most often without explicit solutions if different interconnected tabletops using tangible objects are involved.

2.3 Objectives

In section 2.1, several reference works were presented. They do not however detail the role of the objects. Moreover, they do not provide explanations about how to implement them in a distributed context. In parallel, as explained in Section 2.2., the researchers are very active concerning distributed interactive systems but are not so precise with the tangible interaction. To cross these two domains in HCI, one of our previous contributions was to propose different categories of generic tangible objects called tangigets, which can be used in different applications [41].

In this paper, from this state of the art, our first objective is to propose basic principles to express design choices in the case of UI distribution between tabletops. Specific tangible objects (also called business objects) and generic tangible objects (tangigets) are considered; a set of generic tangible objects are used to support collaboration between users on different tabletops. Our second objective is to apply the approach concretely in an application distributed on two tangible tabletops and to validate it with several groups of users.

3 Proposition of a Design Model dedicated to distributed tabletops with tangible objects

In this paper, the main question addressed is: “How to distribute the tangible and the virtual objects?”.



Fig. 4 The (tangiget) erase

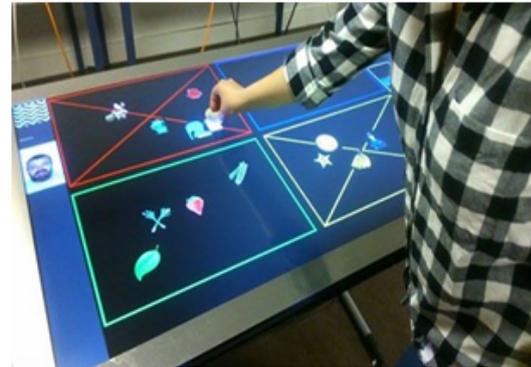


Fig. 5 The (tangiget) erase is illustrated on a classification application

This section proposes a design model bringing a solution in the case of connected tabletops.

3.1 Design of application with tangible objects

A tangible application is composed of tangible and virtual objects which manage the display. A tangible object may be associated to a virtual object in order to provide feedback to the user. Other virtual objects are independent of tangible objects.

Moreover, we can distinguish two types of tangible objects: (1) Business objects dedicated to the application; they are designed according to the task analysis. For instance, Figure 11 shows such objects: these cubes with pictures are specific to the classification task; (2) Tangigets, defined in [41], are generic objects which can be reused in several applications (as copy-cut-paste in GUI). Notably, remote collaboration between users on tabletops is carried out by the use of a set of generic objects (tangigets). The aim of these tangigets is to support an inter-user dialogue using only features offered by interactive tabletops. An example of a tangiget is the rubber (Figure 4). This object is used to cross out an incorrect category in the classification application (Figure 5), and to erase the street names in another application dedicated to road traffic management [31] (Figure 6). In this paper, we focus on the following tangigets. *Identification tangiget* is used to identify users who are currently using the collaborative application and want to enter into collaboration with

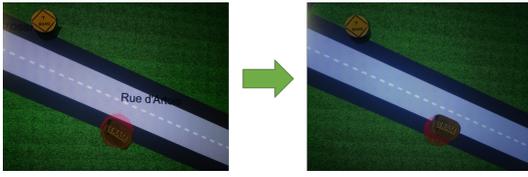


Fig. 6 The (tangiget) erase is illustrated on a road traffic management application

other users. *Task assignment tangiget* is used to organize tasks between different users of the collaborative application. *Starting synchronization tangiget* is used to synchronize the start of the activity distributed on connected tabletops. *Display Mode tangiget* is used to change the display of the main interface according to the user needs. *Request help tangiget* is used to ask for help or ask a question about a step or a detail of the collaborative activity. *Provide help tangiget* is used to offer help about a step or detail following a request. *End task tangiget* is used to mark the end of a task and/or to switch to another task.

3.2 Distribution choices of distributed application on tabletops

To illustrate the various possibilities, Figure 3 shows a global illustration of design choices. The figure shows two tabletops with tangible objects. In this illustration, tangible objects and virtual objects that do not have a real signification because they are not associated to a task.

Objects can be classified in two categories: (1) virtual objects and (2) tangible objects. We consider here that actions can only be launched in the application by tangible objects¹. Virtual objects correspond to the visual display on the screen of the tabletop².

Distribution choices for a virtual object are the following:

- dedicate the virtual object to a local interactive tabletop; the virtual object is not displayed on remote tabletops;
- duplicate on all interactive tabletops to have a global impact. The virtual object can give the same output on all tabletops or can be adapted to the situation. In this case, it can be different in order to give more information to distant users. For instance, in a classification task, a tangible object shows (i.e. is associated with) a virtual object on the local tabletop

¹ Because this work focuses solely on tangible interaction without touch.

² They can also be video-projected onto the surface of the tabletop, as in [31].

which is just a feedback of its presence (and effective detection by the RFID sensors). However, on the distant tabletop, this feedback is not sufficient because the tangible object is not present. So to have the feedback of the presence of a tangible object on a distant tabletop, a picture corresponding to the tangible object is better adapted and understandable for the users of this distant tabletop.

Concerning the tangible objects, the design choices are:

- duplicate the tangible objects to be used on all interactive tabletops with local effect;
- duplicate the tangible objects to be used on all interactive tabletops with global effect;
- dedicate the tangible objects to be used on only one interactive tabletop with local effect;
- dedicate the tangible objects to be used on only one interactive tabletop with global effect.

The choices are made according to the task. If the task is collaborative or shared, the virtual objects should be shared (duplicated) between users, so appear on distributed tabletops (global effect). The role of the tangible object corresponds to the action used to achieve a task, so it is important to know who or where the action has to be performed (dedicated vs. duplicated). Finally, some tasks can be useful only on the local tabletop. In this case, the object is active on only one tabletop, independently of other ones.

For instance, an identification tangiget is dedicated to each participant. It allows the identification of users. Each participant can use his/her identification tangiget in order to inform of his/her presence in the interaction. The application can use this information in order to adapt the local display to his/her preferences according to other participants and also the task. In a distributed context, the adaptation also concerns the distant platform in order to inform distant users of his/her presence. The Figure 7 shows a model of the message exchanges between the actors and the two tabletops in the case of interaction between tabletops when using this tangiget. The description is sufficiently general in order to facilitate reuse in multiple applications.

3.3 Meta-model

In order to formalize the design choices, we propose a meta-model presented in Figure 8. The model presents three packages: task, objects (tangible and virtual) and distribution choices. The relations between all classes make it possible to guide the designer in order to make choices about the distribution.

For instance, to carry out an interactive task, at least

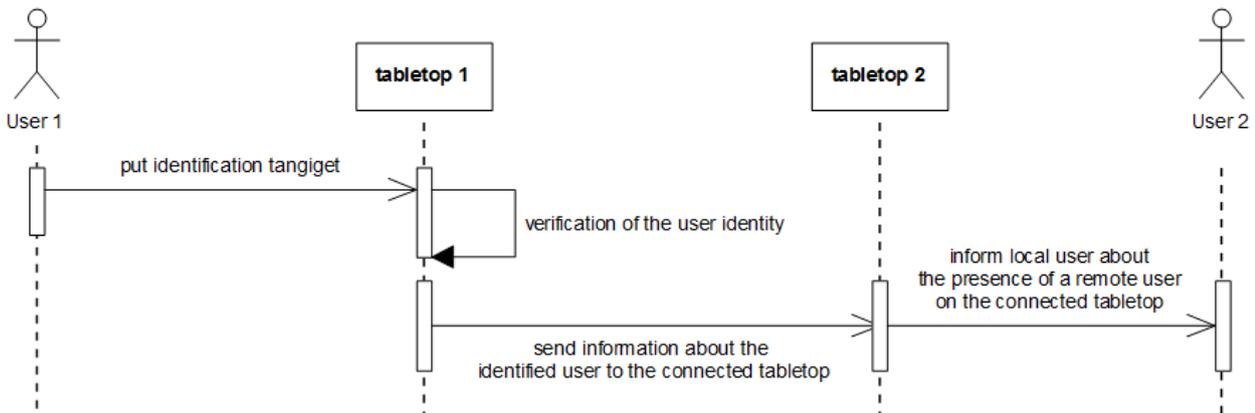


Fig. 7 The sequence diagram modeling the Identification tangiget

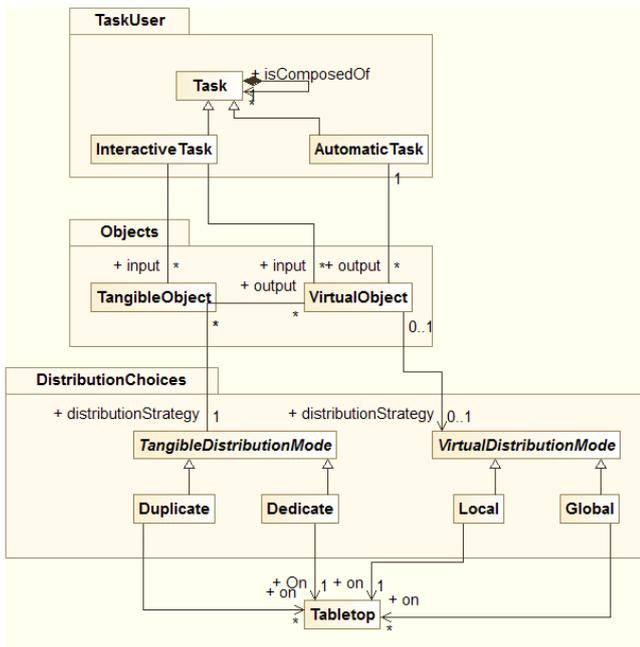


Fig. 8 The class diagram modeling the design choices

one tangible object is needed. This tangible object can be linked with one or many virtual objects to make the outputs. In a distribution situation, the tangible object can be duplicated (distribution mode) on several tabletops or dedicated to one tabletop.

4 Case study: Design of DUI on two RFID tabletops

This section begins with information concerning the implementation. The user tasks are then described. We also explain distribution choices concerning business objects, and concerning tangigets.

4.1 Implementation

As Distributed User Interface (DUI), we use two TangiSense interactive tabletops allowing tangible interaction [33]³. These tabletops use RFID technology to recognize tangible objects placed on the surface, as shown in Figures 9 and 10. In this paper, the contribution is not on the technology used because design models are generic and could also be used with a optical tangible detection. Nevertheless, we justify that these tabletops with RFID capture system used in our research bring some advantages. One of the main characteristics of RFID technology is the notion of safety. Indeed, as the RFID tag is unique, an object X cannot be detected as being an object Y. RFID technology also makes it possible to superimpose flat objects on each other and to have an object like a “basket”, with an RFID tag, in which we could deposit other objects (also tagged). The tabletop is then able to determine the contents of the basket and to define precisely all of the objects it contains. Another advantage of RFID is that it allows the storage of information directly in the objects [35]. We can add that the movement on the tabletop is free because it does not imply overlap with the detection system.

The application uses a multi-agent system in order to manage remote platforms, the role of objects (associated to an agent) [37] and to manage the connection [38].

4.2 User tasks

The application used in our study is a distributed version of an application on an RFID tabletop allowing

³ designed by the RFidees Company; see www.rfidees.fr

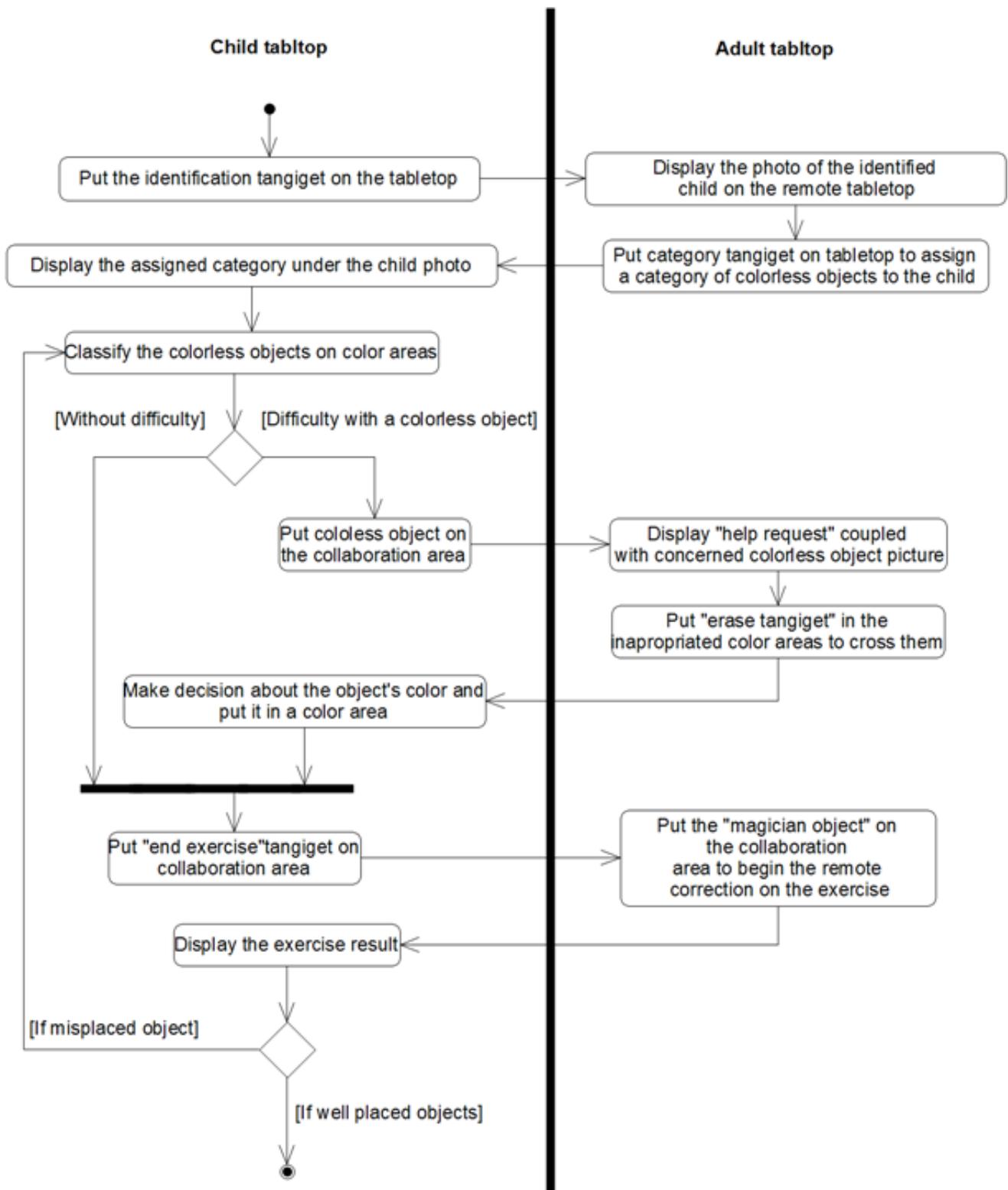


Fig. 12 The activity of the remote user modeled by a UML diagram



Fig. 9 The interactive tabletop with the children view



Fig. 10 The interactive tabletop with the Parent view

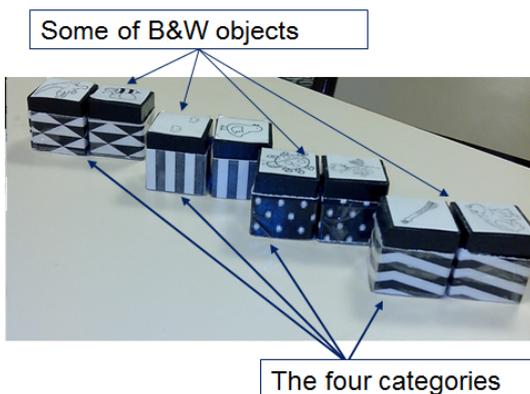


Fig. 11 The (business) objects to classify which have lost their color, and the four categories

the learning and recognition of colors; the initial version was presented in [32,36]. Most of the evaluation results are available and evaluated in [36]. The learning application is for childhood learning (in compliance with the teaching curriculum for preschools in France). A teacher proposed a simple application, in which children must put a set of objects that “lost their color” into the appropriate color box (the color box can be seen in Figure 19). For example, a colorless image of the sun would need to be placed into the yellow area. A picture of objects is shown in Figure 11. The set of objects are different for each child. There are four sets of objects (the different pictures associated to each set are shown in Figure 11). This exercise is appropriate for children aged 2 to 5 years old. In the centralized application, the child was required to determine what the image represents, establish the image’s appropriate color, and place the object in the corresponding color box on the interactive tabletop. Once the objects are placed, the child is invited by the teacher to verify them with the business object Magician.

In the current paper, this application has evolved in order to introduce distribution and supervision. The task is now distributed between two tabletops. On the tabletop named *children*, the classification task is the same as in the previous work, described in the last paragraph. Some changes were made such as the collaboration area, display area and some tangible objects in order to support the collaboration task. On the *adult* tabletop, a parent, teacher or more generally supervisor can see what objects are put on the *children* tabletop. This (or these) user(s) can help the remote users specifically for an object by crossing out the colored area not concerned by the object, putting the magician to launch the answer to the exercise. The activities are modeled by an activity diagram (Figure 12). We can see that firstly, the children place their identification objects to indicate their presence. The supervisor places the category objects to indicate which set of objects is for him/her. The children can operate the classification while parents or teacher supervise. And if a child has a difficulty with an object, he/she puts the object in the white area (collaboration area) in order to request help. The supervisor can cross out a wrong area (one, two or three) and when the child takes the object out of the collaboration area, the supervisor can erase the crosses. When the children have finished, they put another particular object on the tabletop and the supervisor can place the magician to launch the correction of the exercise.

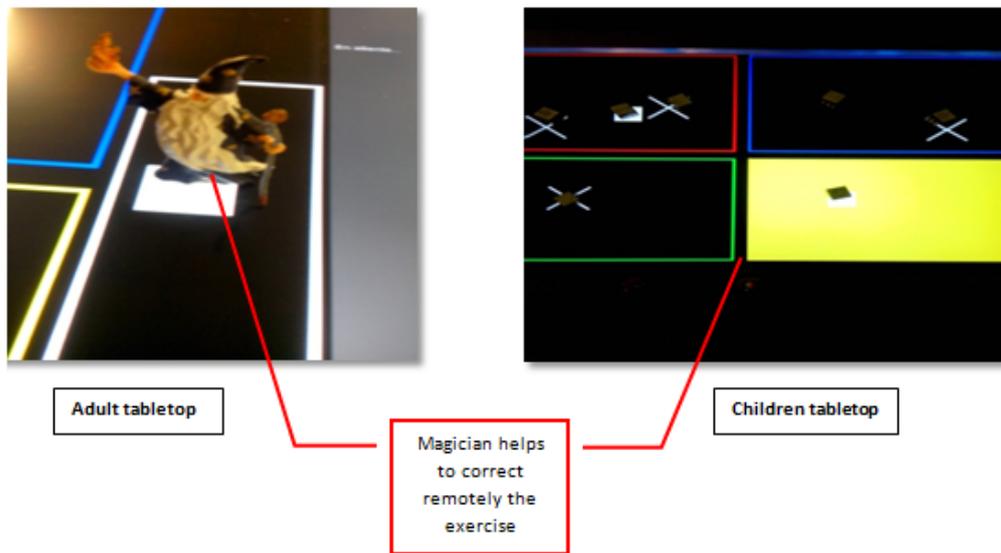


Fig. 13 Magician object

Table 1 Business objects

Business Objects	Virtual vs. Tangible	User
Cubes with picture	tangible	child
Color areas	virtual	all
Magician	tangible	teacher

4.3 Distribution choices concerning business objects

In the centralized learning application, business objects are described in Table 1. **Cubes** present various colorless pictures. The final users are very young children learning colors; they have to arrange the cubes in **color areas** according to dominant colors.

These cubes are divided into four categories (one per child); each category contains eight objects of varying levels of difficulty. When the teacher (also called supervisor or adult in this paper) who manages the practical exercise, decides to stop or to guide the children, he/she places the object called **Magician** on the tabletop. When it comes to the same application in a distributed mode, these business objects are kept and adapted according to the design models proposed in Section 3. Some choices are made concerning these business objects (cf. Table 3).

We consider two tabletops, one dedicated to children and another dedicated to the remote supervisor (teacher). On the child tabletop, the task will remain almost the same. Children have to put the cubes (tangible objects) in the color areas (virtual objects). On the distant tabletop dedicated to the supervisor (adult user), the virtual color area is duplicated and when a child puts a cube

on his/her tabletop, the picture is displayed to the supervisor on the distant tabletop.

Once the children have finished placing all objects, the supervisor on the distant tabletop can provide a remote correction. In this case, the supervisor puts the magician object (not duplicated on the other tabletop as it is associated to the teacher) on his/her tabletop. Misplaced objects will be crossed out on the child table (global effect). If an area contains only objects that belong to it, its dominant color will be filled (Figure 13).

4.4 Distribution choices concerning tangigets

As described in the Section 3.2, the application uses a set of tangigets useful for remote collaboration. Table 2 shows those objects and their main functionality in the application.

Personal card (avatar). To identify each person on the child table, users are asked to put their identification object on the tabletop; it is a personal object or card that expresses the identity of the holder. In the case of this application (see Figure 14), an avatar⁴ is chosen to represent each child (dedicated object). On the adult table, the photo of the identified child is displayed (global effect).

Category cube. Each set of eight cubes of colorless pictures corresponds to a category. Four categories are available: dotted, vertically striped, diagonally striped

⁴ created using a Playmobil® figure.

Table 2 Tangigets: task and behavior

User task	Name of tangiget	Tangible/Virtual	Behavior
Identification	Personal card	Tangible	Used to identify the person present remotely and ready to play
Task assignment	Category cube	Tangible	Assign a goal (eg. category of objects) to the person identified
Starting synchronization	Start object	Tangible	Start the application on the two connected tabletops
Display Mode	Focus	Tangible	Display the results of the exercise (textual representation)
Request help	Collaboration area	Virtual	Request remote assistance by placing in this area object(s) requiring help
Provide help	Erase	Tangible	Offer help by crossing color areas
End task	End exercise	Tangible	Indicate the end of the exercise for each user

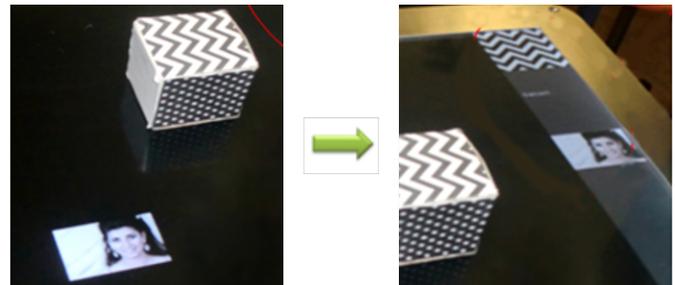
Table 3 Business objects with distribution option

Business Objects	Virtual vs. Tangible	User	Dedicated vs. shared/duplicated	Local vs. global effect
Cubes with picture	tangible	child	dedicated on the children tabletop	global effect
Color areas	virtual	all	shared	global effect
Magician	tangible	parent supervision	dedicated on the Parent tabletop	global effect

**Fig. 14** Personal card: avatar

and triangle. Once a child is identified, the adult (supervisor) places a multi-faceted object *category* (dedicated object) on his/her tabletop with the picture of the selected category on the top (Figure 15). The adult can assign one category to each identified child. The picture of the category is displayed on the child tabletop (global effect). The category cube can also be used if the supervisor wishes to display the remote placed colorless cubes by category. When placed in the collaboration area, the objects belonging to the selected category are the only ones to be visible.

Start object. To synchronize the start of the application on the two tabletops, the adult puts the *Start* object (dedicated object) in the collaboration area (Figure 16). The interface will be displayed at the same time for users on interconnected tabletops (global effect).

**Fig. 15** Category cube**Fig. 16** Start tangiget

Focus. The adult has an object called *focus* (dedicated to his/her tabletop). When placed in the collaboration area, the information provided by remote tabletop (children tabletop) is displayed; in this application the information is the result by color area (Figure 17). This tangiget helps the user on supervisor tabletop to identify the misplaced objects (local effect).

Collaboration area. This is the only tangiget (in this application) which is only virtual and be used by other tangible objects (Figure 19); its main role is to identify the tangible object placed on it and to display the desired result according to this tangible object on the remote tabletops. The display also depends on the stage

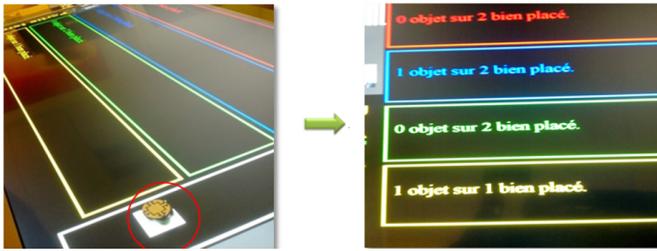


Fig. 17 Focus tangiget

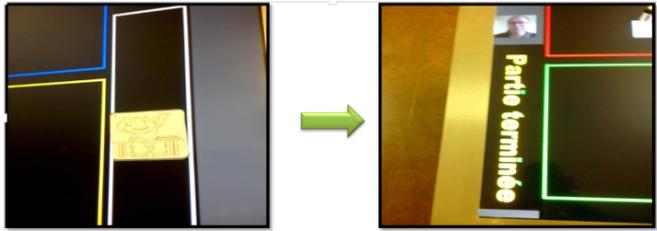


Fig. 18 End Exercise tangiget

of the exercise. This object is duplicated on all tabletops; it is used to share information (global effect).

Erase. If the child encounters a problem with the identification of the color of a colorless cube, he/she puts it in the collaboration area. The help request is then displayed on the remote tabletop with the image of the object in question (global effect). If the adult decides to help him/her, he/she could eliminate the colored areas which are unsuitable for the concerned object. He/she places the *erase* tangiget (dedicated object) (Figure 4) in the color area which is to be crossed out on all the tabletops (global effect) (Figure 5).

End exercise. Once all the child's colorless cubes are placed on color areas, the child places his/her *end exercise* card on the collaboration area (dedicated object). A notification is then displayed on the adult tabletop (global effect), so he/she can start the remote correction of the exercise (Figure 18).

To conclude with the application, one can notice that to support distribution of shared and remote applications, tangigets are used with various combinations in the choices. Table 4 gives the summary of choices made in order to provide tangigets to such distributed applications. The following section describes the evaluation performed to validate these choices.

5 Evaluation

As already mentioned, the learning application in a centralized context was evaluated in previous work [32,36].

Table 4 Tangigets: distribution choices

Name of tangiget	Dedicated	One/all tabletop	Local/global effect
Personal card	dedicated	one tabletop	global effect
Category cube	dedicated	one tabletop	global effect
Start object	dedicated	one tabletop	global effect
Focus	dedicated	one tabletop	local effect
Collab. area	duplicated	all tabletops	global effect
Erase	dedicated	all tabletops	global effect
End exercise	dedicated	one tabletop	global effect

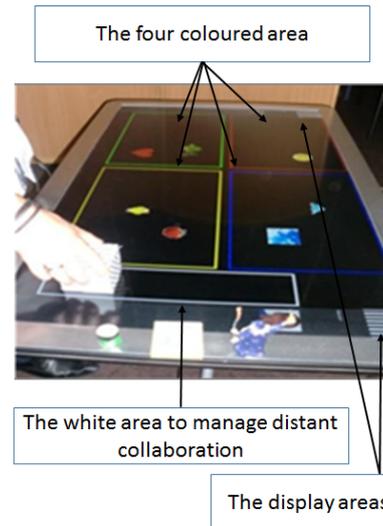


Fig. 19 The common areas: the four colored areas, the collaboration area and the two display areas

The evaluation concerns the supervision (adult tabletop) in order to validate the design choice dedicated to the distribution. In order to facilitate the evaluation, all users are adult. The children's task is a simple classification task. Its advantage is to imply adults. It was easy in the protocol to ask participants with a child's role to make (simulate) errors in order to lead to supervision and collaboration situations.

5.1 Protocol

We recruited twelve groups of three participants each, who were not familiar with the use of tabletops. These 36 participants have a globally homogeneous level of education (master's degree level or higher). Each group consisted of three people, two in the role of children and the third to represent the adult. Members of each group knew each other and had worked together before; subjects were colleagues, friends, members of the same family, or married couples. Participants were aged 23-

49 years old (the average age was 27 years old)⁵.

A presentation of the system and its functioning as well as the functioning of each tangible was given to the twelve groups of three participants. It was followed by a familiarization phase with the interactive tabletops during which the participants were encouraged to try the application and all items offered and to ask questions freely. After this phase of familiarization with the system, tests were started with different scenarios provided. We designed three conditions that varied aspects of the use of the help request and the correction of the exercise. In these different conditions, instructions were provided to users of the child tabletop. We aimed to get a definite number of mistakes and requests for help.

To simulate a remote collaboration, participants were located in the same room; the two tabletops were separated by a folding screen to prevent users of each tabletop from seeing the contents of the other tabletop. Moreover, to prevent the Parent participant (supervisor) from being disturbed by possible natural discussions coming from the child tabletop, he/she had a headset with music.

After the study, each participant had to complete a questionnaire. The questionnaire firstly concerned information on the usability aspects and user satisfaction with the system. Secondly, he or she had to fill in more specific information on generic objects, their ease of use and significance in relation to their role set by the designer.

5.2 Results

Observations. The evaluation was conducted in the laboratory in a room equipped with interconnected tabletops, a computer to run the interactive tabletop process and cameras filming the progress of the test on the interactive tabletops. Different types of data were captured, according to the steps illustrated in Figure 20.

As a first step (Figure 20 (1)), we began by evaluating the usefulness of the tangibles used to collaborate remotely and to communicate the information and details of the collective activity on the interactive tabletops.

The main goal of this step was to capture the understanding rate of each tangible by his/her user either through the significance of the object's shape, operation or handling. Also, we wanted to test if the partic-

⁵ During this first evaluation, the choice was to involve only adult participants, and to study the impact of tangibles and distribution choices. For the adults (simulating children in our case), the main task can be considered as a classical classification task. Previous evaluation involving children on the classification task had already been validated by a previous study [32,36].

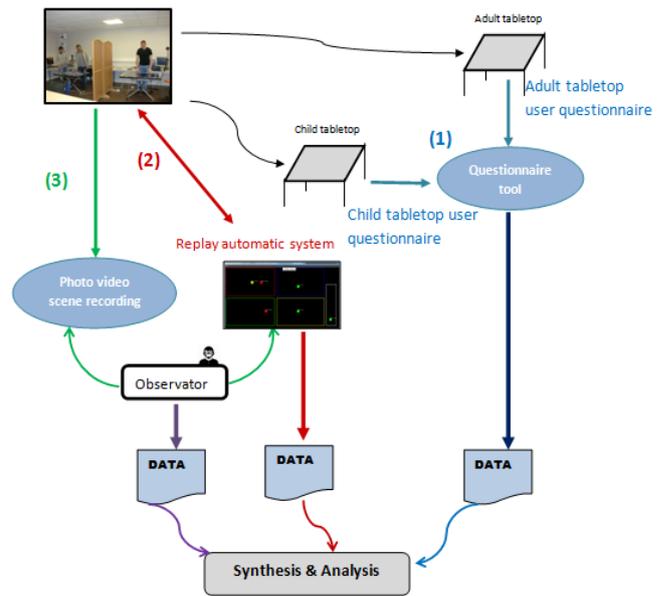


Fig. 20 The protocol to capture observation data

ipant used the right tangible at the right moment or not during the collaboration. That is why the different participants of the two interactive tabletops answered different questionnaires. Indeed they did not use the same generic objects.

For the second step (Figure 20 (2)), we had to study and extract test statistics using an interactive application. This application records the round played on the two interactive tabletops. The viewer displays and replays the round (cf. Figure 21). In fact this data allows to measure the response times after each remote communication (total time for each action or sequence of actions), to study the time taken to understand the feedback corresponding to each object put by the remote collaborator and to calculate the error percentage of the users of the distributed application. Figure 22 shows an example of interface statistics. The results displayed on this Figure concern a particular game. On the left part, the time, the number of errors and the number of requests for assistance are displayed. Then more precisely, on the left part, a graph shows the objects which cause difficulty and the number of errors. On the right part a bar graph gives the color in which the objects have to be placed. Finally, at the bottom, the graph shows the rate of effectiveness of the eraser tangible object.

For each game, an XML file is produced with different parts. The first one is dedicated to the avatar, the second to the start tangible. The XML file also contains the information concerning the placed objects and the color of the area in which each was placed. The request

Table 5 Tangigets: questionnaire results

Question	The object has a significant role					The object is easy to handle					Total
	Do not agree	Tend to disagree	Fairly agree	Tend to agree	Strongly agree	Do not agree	Tend to disagree	Fairly agree	Tend to agree	Strongly agree	
Personal card	0	2	1	5	16	0	1	0	4	19	24
Category cube	0	0	1	4	7	0	0	0	4	8	12
Start object	0	0	1	1	10	0	0	0	2	10	12
Focus	1	2	5	1	3	0	2	2	1	7	12
Collab. area	0	1	2	9	24	0	1	2	9	24	36
Erase	0	1	0	3	8	0	0	0	3	9	12
End exercise	1	1	1	7	14	0	0	0	3	21	24

alone so no conversation was possible; (2) the two tabletops were located in the same room and this participant was isolated with an audio headset so he/she could not debrief while using the application. However, it was possible to debrief this participant during the questionnaire step.

Questionnaire. A questionnaire was used to seek the opinions of participants on the usability of tangiget objects, the meaning of objects, and ease of understanding of the remote communication with the other tabletop. We used a Likert scale with five points. The start order of the tested scenarios was designed so as not to influence the user responses.

Questionnaires concerning the tested items were distributed to the users according to their roles in the application. That is why the 12 participants on the adult tabletop answered questions about five objects: Magician, Category Cube, Start, Erase, Focus. The 24 participants on the child tabletop responded to questions about the three objects concerned: Identification, collaboration area and End Exercise.

According to user responses for the question “The object has a significant role”, we can classify objects into two categories:

- Objects that have a high matching with their allocated roles and forms are: Identification, Category cube, Start, End exercise and Collaboration area;
- Objects that have a medium matching with their allocated roles and forms are Focus, Erase and Magician.

According to user responses for the question “The object is easy to handle” - note that this question is clearly in relation with the distribution choices we can classify objects into two categories:

- Objects whose shape is very good for their use and handling (Identification, Start, End exercise and Collaboration area);

- Objects whose shape is moderately good for their use and handling (Magician, Focus, Erase and Category).

We note that none of these objects/tangigets was low classified for both questions, which proves that all the proposed objects were accepted in general. The results are available in Table 5.

Several objects have a global effect, for example magician (business object) and erase (tangiget) are used by the supervisor and have an effect on the remote tabletop. A question is dedicated to these objects for the participants on the child tabletop: “The correction of the exercise is clear to correct mistakes”. The result is that 0 participants disagree strongly, 1 does not tend to agree, 1 agrees fairly, 10 tend to agree and 10 agree strongly. These results show that the design choices relative to these objects are validated.

Satisfaction. The usability of the distributed interactive application was measured with a questionnaire using the System Usability Scale (SUS) [9]. SUS is a standard metric from the usability literature. It has been used in hundreds of usability studies [3]. For avoiding any biases, these questions alternate between positive and negative statements about the evaluated system. In this questionnaire, a 5-point scale ranging from 1 as strongly disagree to 5 as strongly agree was used for the measurement. The overall scale gives a global view of subjective usability assessments (maximum score: 100 points). The SUS scores were calculated for the 36 participants. These scores are listed in Table 6. As summarized in this table, the mean SUS score is 84, the median is 85, the maximum is 100 and the minimum is 62,5. Even if the SUS questionnaire is not a priori designed to evaluate collaboration and group interaction, these scores indicate that the global approach was appreciated by the subjects, and that the distributed interactive system is globally easy-to-use. This is a promising result. It complements the results obtained from the analysis of the other questionnaires which were more

Table 6 SUS scores descriptive statistics

Number of participants	Mean	Median	Min value	Max value	Standard Deviation
36	84	85	62.5	100	10

centered on the tangible generic objects used (see Table 5).

5.3 Positioning of distribution aspects

In this part, we use the criteria (heterogeneity, openness, security, scalability, Failure handling and Concurrency) proposed by [66] and inspired by [12] in order to evaluate the DUI proposed.

Heterogeneity is about the quantity and the variety of resources. In this paper, the proposition is general so it can be used with as many resources as possible. In the same way, the case study focuses on two tabletops though the proposed principle is right with more interconnected tabletops. However, the principle is focused on tangible interaction; for another types of interaction, other works exist.

Openness is the capacity to support new resources without a major effort. With the architecture used by the tabletops (and consequently in the case study), openness is managed with the multi-agent system and in particular with the JADE [5] platform. The architecture is used with two tabletops although it is possible to add new resources without changes; indeed the distribution principles remain effective.

The security criterion integrates confidentiality, integrity and availability of shared resources. The integrity and availability are managed in the case study by the architecture. The confidentiality is managed by the type of task and the distribution choices proposed in the paper. The scalability remains effective when there is a serious increase in the number of resources or number of users. This criterion is not really evaluated by the case study. Evaluations with more users and more resources have to be performed to validate this criterion.

The Failure handling (the resources used can fail and lead to inconsistency problems) is managed in our case study by the multi-agent system (MAS). Obviously, if a platform such as the tabletop fails, interaction is not possible with it and the user has to find another resource (platform) to interact with.

Concurrency, i.e. certain resources (e.g. tabletop) cannot be used concurrently, is respected. The multi-agent knows the IP address of the resources; the IP address has to be unique so the MAS cannot affect two (or more) resources (displays and RFID capture manage-

ment) to the same IP address.

In DUI, the transparency particularly concerns the location of resources because it is important in order to use the adequate resources. In the context of the paper, the resources are defined and known though the transparency can concern more particularly the distribution choices. We have seen that privacy and the sharing of information is a key point in the DUI. The transparency on what is local vs. global is very important for the users to know the consequences of their actions. Now that the UI and the distributed aspects are globally validated relatively to these criteria, we want to discuss certain design choices.

6 Discussion

Obviously, an evaluation is never perfect and can be improved in order to validate other hypotheses. For example, in our case study only one principle was used by a tangiget. Behind the design choices proposed, we attribute a choice to each tangiget, according to its role and the task that it performs. To complete the validation, other choices should follow for comparison.

However, the evaluation enables us to validate some parts of the proposition. In particular, for such distributed applications, a set of objects (virtual and tangible) have first to be implemented (by the designers /developers) and then used by the participants. These participants are not children, as initially specified for this application, although the business objects used were preliminary validated in another study involving very young children with one tabletop [36].

In reality, there was one problem in the previous design; each cube was colored to be grouped and affected to a child. The color used on the cube caused some confusion between the color of the cube and the color of the object. We have corrected it in this case study: the cube of the application uses graphic schema. We have not observed any confusion in the new version of the application. Moreover, some tests were executed with children though not with a strict protocol and questionnaire. An extension of this study in an ecological context would be preferable, to confirm the adequate use of the objects (and the associated design principles).

We can now discuss another choice made in the case study. The distribution of the application was made following the role of users; indeed we use a child tabletop and another one for a supervisor (for instance a parent or a teacher). We wanted to begin with a role per tabletop and to validate the design principles with this configuration. The following step should be to mix user roles on a tabletop: for instance one adult and one child

on a tabletop and two children on the second tabletop. It would be interesting to perform other evaluations considering such variants.

Finally, the meta-model was used to support choices in the design of this distributed UI with tangible and virtual objects. The important contribution is actually taking into account the task type to support the design choices. This model can be extended to other types of interaction, such as virtual or augmented reality, and more generally mixed interactive systems in which one or several tabletops can be involved [39]. Such consideration was not covered by the other works presented in the related work section.

7 Conclusion

New perspectives are offered by distributed user interfaces. This paper was focused on the distribution of user interfaces between interactive tabletops with tangible objects. In this case each tabletop is equipped with two main types of tangible objects: business objects specific to the application (also called business objects), and generic objects usable in different types of applications (called tangigets). Such interactive applications lead to new design problems due to (1) the use of tangible and virtual objects on each tabletop, (2) the necessity to collaborate and exchange information at a distance.

In this paper design principles have been proposed for such new distributed systems using tangible interaction. These principles have been used for the design of an innovative distributed application for the learning and recognition of colors. In this case, a classification exercise is performed on one tabletop. It is supervised by one or several users (teacher(s) or parent(s) for instance) on the second tabletop. Difficulties during the exercise may lead to a remote collaboration. Different types of tangible objects support the tasks on each of the tabletops. This distributed application has been detailed, and the functioning of several generic objects has been illustrated.

A study has been conducted with twelve groups of three users. Usability and satisfaction criteria have been considered (through observations and questionnaires). The results are promising and show the interest of the distributed approach, as well as the facility to use the generic tangible objects (the tangigets). In future work we aim to test such tangigets with other more complex applications to verify if collaboration remains easy/possible. Different configurations can be envisaged and evaluated, with or without children as participants.

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