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Management of distributed RFID surfaces: a cooking assistant for ambient computing in kitchen

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Abstract

Interactive tabletops are used to support interaction when designing applications. The design is generally displayed on the detection surface, but in some cases, the display uses other surfaces in a distributed way. This paper proposes some additions of an existing architecture. This new architecture aims for managing distributed surfaces with agent concepts of a Multi-Agent System. The Multi-Agent System proposed in this paper is adapted to the exploitation of tangible and virtual objects allowing them to exchange information. The principles for designing an original cooking application on a distributed interactive tabletop are presented. Multi-Agent System is based on a set of wishes with advanced culinary search capacities. We propose a tabletop equipped with RFID technology and a distributed display to suggest additional information. This tabletop allows interactions with tangible objects (real ingredients) to take place and suggests recipes to the user. The proposed application illustrates the possible use of a tabletop in such an ecological setting. Finally, results obtained from two complementary evaluations are briefly described to validate the new architecture and the cooking application using it.

Keywords:
Multi-Agent System; Distributed Surfaces; Tangible interaction; Ambient Computing; RFID; Cooking; Tabletop; TangiSense

1. Introduction

Interactive tabletops introduce a novel way to communicate. These platforms can be used individually or collectively. Today, tabletops are mainly multi-touch. Our focus is on tangible interaction, which enables users to put objects and hands on the tabletop without disrupting the system. Tangible User Interfaces (TUIs) emerged two decades ago;

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there has been a shift from physically augmenting the graphical user interface[1] to digitally augmenting everyday artifacts[2,3]. The goal of tangible interaction is to be more natural.

The interactive tabletop used for this research has a LED display and RFID sensors to detect tags uniquely; its detection precision is about 1 cm. This tag detection allows the tabletop to identify the position of (1) the common objects dedicated to the use (cooking here), and (2) other tangible objects used as *interactor* named Tangigets[4]. In this application, the tabletop is connected to a supplementary display to present information to the user in a distributed manner (Fig. 1). The proposed application is cooking. Several studies[5,6] and websites[12] suggest interactive cookbooks

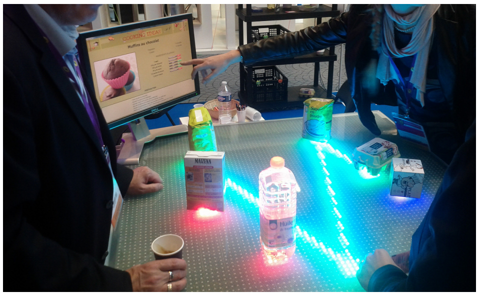


Fig. 1. The cooking assistant distributed on two surfaces

for the kitchen workspace. For instance, Bonanni *et al.*[7] suggest augmented reality techniques for assisting people throughout the cooking process in a fully interactive kitchen. Another way to support cooking, proposed by Krantz *et al.*[8], is with an augmented cutting board and a sensor-enriched knife, which enable the environment to determine the type of food handled during meal preparation.

The research discussed in this paper pertains to a cooking assistant that adapts to distributed surfaces. An *in situ* illustration of the tabletop is shown in Fig. 1 with a final view of ambient computing in kitchen. The objective is to imagine a regular table or kitchen counter and propose an interactive approach (using a tabletop) and a cooking assistant to link real (tangible) ingredients and recipes to a set of constraints given by the user.

The article is structured as follows. Section 2 presents a state of art which focuses on distributed user interface (DUI) and assistance in kitchen. Section 3 proposes a software architecture for managing distributed surfaces with agent concepts; an illustration of the overall functioning is also provided. Section 4 presents *Cooking Ideas*, an original application using the proposed architecture. This application suggests recipe ideas using everyday ingredients equipped with RFID tags. Section 5 sums up the technical and user centered evaluations performed. The paper ends with a conclusion and possible perspectives for future research.

2. Related Work

Distributed UI design and evaluation is currently an important research topic[9]. For instance, Tang *et al.*[10] use distributed displays to facilitate remote collaboration; the users interact on interactive tabletop and see other ones on screens (one user per screen) set up vertically around the table. Kim *et al.*[11] propose a framework named *Hugin* to distribute information visualization. The framework is dedicated to co-located or remote, synchronous or asynchronous collaboration, with the tabletop for example. The *connectable* system[12] aims to connect several horizontal or vertical surfaces dynamically in order to support face-to-face collaboration/meetings. The goal is for users to manipulate their surfaces independently, and then couple them to merge the information.

An interactive and collaborative game *TraInAb* (Training Intellectual Abilities) is proposed to stimulate people with intellectual disabilities[13]. This system couples a mobile user device that detects tangible objects (equipped with RFID tags). The information is transmitted to the database. The steps are executed so that information is fed back to the mobile device and the main interface (PC and video projector). Melchior[14] suggests using a Multi-Agent System

[1] http://www.bbcgoodfood.com/
[2] http://www.grandmaskitchen.com/

to distribute the user interface to multiple devices (not particularly tangible). Finally, the *Ensemble* architecture is suggested by Branton *et al.*[15] to encourage exploratory development of distributed, tangible and collaborative applications by limiting the impact of changing components.

In the literature, tabletops have not really been exploited for cooking. Gaver *et al.*'s History Tablecloth was designed as a digital layer that sits on top of a dining table. It traces the food prints of the objects placed on it, thereby subtly revealing various social patterns within the home[16]. Ju *et al.*[17] propose to use the RFID[18] technology in the context of an interactive cookbook for the kitchen counter. With the tabletop, when the user places the ingredients on the table, the recipe, videos and others media are displayed. The user interacts with this system in a tactile manner (a camera detects an image bearing a symbol). The interaction takes place on the table using a projector system.

Some researches propose distributed user interfaces in the kitchen. Uriu *et al.*[19] suggest using cooking equipment and propose displays to guide the user in making a recipe, as shown in Fig. 2. This system helps users control the cooking flame, move the pan properly, and cook sequentially according to instructions via sound, light, vibrations, pan projections and the monitor display, which is placed above the cooktop.

Fig. 2. Cooking a Carbonara Recipe, mediated by *Panavi* (adapted from [19])

Such studies help demonstrate the interest in using *physical* objects in virtual environments, like cooking assistants. In our research, the ingredients are tangible objects. A specific object (*Tangiget*[4]) helps initiate a criteria search. Other tangible objects could be coupled with an interactive table to further refine the recipe search. The proposal focuses on a distributed user interface (interactive table and another UI). The table used has a layered architecture that includes a Multi-Agent System (MAS). The suggestion is to use a MAS to provide comprehensive user support and manage distributed interactions. This will be presented in the following Section.

3. Proposal for a Tabletop architecture augmented for distributed surfaces

This section presents a software architecture for managing distributed surfaces with agent concepts. The proposed architecture is based on a combination of a Multi-Agent System (MAS)[20] and Human-Computer Interaction (HCI)[21] concepts to adapt the user interfaces. This architecture is based on the formalisms defined in[22,23] to design applications on interactive tabletops. These formalisms are used to define the different types of agents (virtual or tangible) and their management on an interactive tabletop surface. This architecture is composed of four layers:

- The hardware layer represents the tabletop surface detection. It is used to receive the signals provided by objects identified by a barcode, an image or an RFID tag, for example.
- The middleware layer receives and analyses information from the hardware layer. Information is associated with objects. The events are related to objects are provided by the detection technology. Modifications in position are communicated to MAS layer.
- MAS manages the specificities of the applications associated with the tabletop and screen(s). This layer is able to create an instance of any virtual or tangible object type in an application, and an underlying HCI.

- HCI has the responsibility of communicating with users; it makes it possible to transmit virtual information through distributed user interfaces.

We propose to increase these formalisms to design and implement heterogeneous applications for interactive tabletops with distributed surfaces. The system takes into consideration the characteristics of environmental dynamic, a set of displays and the user's profiles. This new architecture integrates the exchanged messages between the software entities described on Fig. 3. This figure shows the mix between different kinds of display surfaces that are not necessary on the tabletop and takes into consideration the interest in displaying information across several complementary displays.

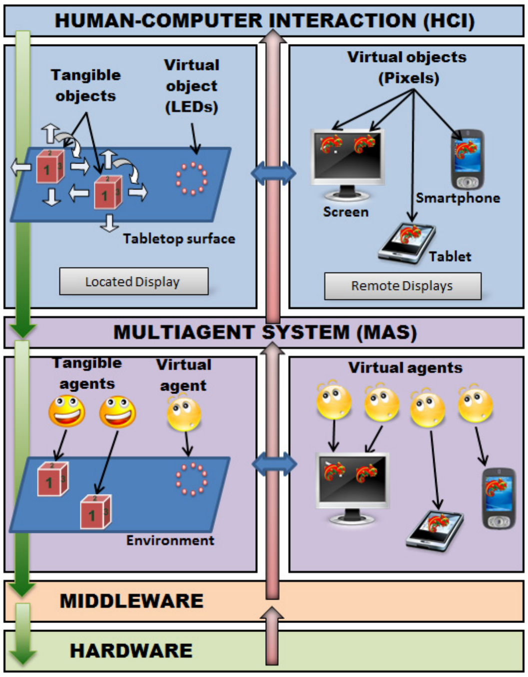


Fig. 3. The software architecture

In this case, the sensor surface is similar to the display surface and the entities (e.g., the agents of the MAS) receive the sensory inputs from the interactive tabletops. We propose an instanciation of the architecture considering multiple complementary displays dedicated to tabletops (e.g., several displays used simultaneously). The display areas differ in size, thickness, resolution, layout (vertical or horizontal) and light source (e.g., LED, LCD or plasma). In addition, the display is located on the tabletop or distributed surface to facilitate user interaction. In this case, the display can be done in parallel to the sensor surface as well as in any other type of visual media with varying characteristics.

The advantage of this architecture is that it provides independence from the sensing surface and is not limited to a single display surface.

Distributed user interfaces can be in one of two categories: (1) in **located display**, the display surface is similar to the sensing surface; in **remote display**, (2) the display surface (screen, Smartphone, tablet) has technical specifications (e.g., size, orientation, resolution) that differ from the sensing surface. The number of remote displays is unlimited and user interactions can be achieved in a remote way.

In this software architecture, there are also two kinds of entities: (1) tangible objects (objects that can be manipulated by one or several users) and (2) virtual objects (objects that can be displayed by one or several display types simultaneously) in the HCI layer. In the MAS layer, we distinguish (1) tangible agents (agents connected to tangible objects that react to environmental modifications emanated from object movements) and (2) virtual agents (agents associated to virtual objects).

In this architecture, communication between layers is a key point. Communication is represented with arrows in Fig. 3. These arrows represent how the distribution of a data stream can switch the different layers. These arrows are oriented and define the entry and exit points between layers. For example, when a user moves a tangible object, information (position, shape, side) will be transferred between the different layers, from the lowest to the highest level. Once the MAS layer receives information from the lower layer, the system agentifies an agent (called a tangible agent) for each tangible object placed or moved on an interactive surface. Tangible agents are agents situated in a plan corresponding to the detection surface. These agents are responsible for the consistent execution of behaviors associated with the object as well as interactions between the tangible object and its environment (*e.g.* modifications resulting from the object's movements). After collecting the data, the agent communicates with the HCI layer through a shared Java class. This class is read by the HCI layer and adapts the user interaction.

For located or remote displays, the process of creating virtual objects is the same. The HCI layer transfers information on a virtual object to the MAS layer. This object is associated with an agent (called a Virtual Agent) that is endowed with a graphical representation on the interactive medium or on another kind of display. Unlike tangible objects, virtual objects are able to change forms, colors and size and can disappear anywhere in the application.

The overall consistency of the system is attributed to agents. Agents (tangible and virtual) are able to communicate and exchange information on their position and shape following the principles of the Internet of Things[24]. They can react to the environment in accordance with the instantiated application.

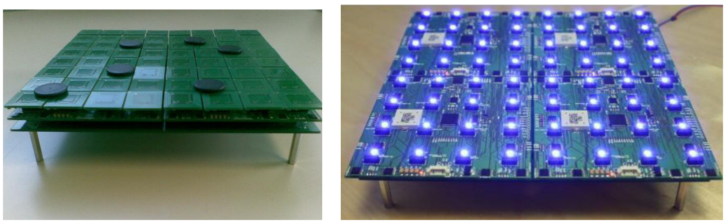
We have seen that the layered architecture is based upon a hierarchy of four abstraction layers. Each layer is composed of knowledge and skill according to its level. The MAS links an object to an agent with a set of behaviors. It also plays the role of controller if we make a parallel with Model/View/Controller (MVC) architecture[25]. In this way, information can be transmitted to the various HCIs (views), which are known to ensure consistency in the information display (e.g., located or remote display).

4. Implementation of a MAS-based cooking assistant on interactive tabletop

This section presents the implementation of the tabletop architecture dedicated for distributed surfaces on the interactive tabletop *TangiSense*. We propose a cooking assistant to illustrate the management of distributed surfaces.

4.1. RFID surface: hardware and middleware context

MAS-based cooking assistant has been designed on the interactive TangiSense tabletop. This tabletop described more precisely by Kubicki *et al.*[21] presents direct interaction via tangible objects and uses RFID technology to detect overlapping objects. This technology allows store information about different objects. This information can include the history of the object's movements or the users' or objects' authentication information. To detect and locate objects with RFID tags, the tabletop is composed of 25 tiles. Each tile contains 64 antennas (8x8) (Fig. 4(a)) for collecting data from remote RFID tags. Each antenna is equipped with four LEDs (light-emitting diodes) (Fig. 4(b)).



(a) One tile with RFID Tags (b) One tile with lighting LEDs

Fig. 4. Tiles with 8x8 RFID readers and LED display

A first technical solution for providing visual feedback (e.g., tabletop display) to the various users is to use LEDs in applications instantiated on the table (for example, LEDs are used to indicate the detection of an object or to draw a shape). The second solution is to use a remote display. This display allows the user to provide a complementary display. This display can be used alone or in combination.

At the application level, tangible objects associated to tangible agents have meaning and special roles to play depending on the application, and need to dynamically manage interactions between them, with virtual objects associated to virtual agents and with users.

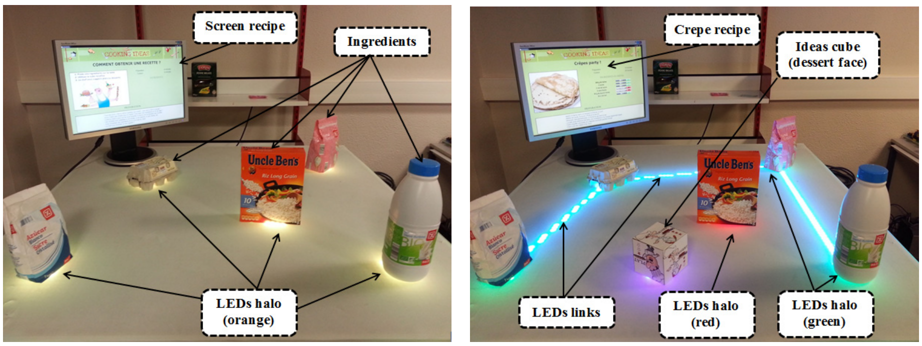
4.2. MAS-based cooking assistant

We propose in this paper a cooking application for the software architecture and the agents concept presented in the previous section. This application, called *Cooking Ideas*, aims to simplify the life of users. The goal is to learn the user's habits and suggest recipe ideas using everyday ingredients (e.g., milk, flour and sugar).

Fig. 5 shows the *Cooking Ideas* application on the interactive tabletop. The tangible objects used are the ingredients, the *Ideas Cube* described below and a user card. To be identified on the tabletop, the packaging of different ingredients and all tangible objects have one or several RFID tags. Virtual objects are links between ingredients, the halos under ingredients and elements on the recipe screen.

The user card is used early on in the application to identify a person in the system. The user puts this card on the tabletop to transfer a set of wishes to the application. The user information pertains to restricted ingredients, special diets (for diabetics, pregnant women, people with religious dietary restrictions), cooking experience, user preferences (e.g., time needed to complete the recipe, maximum price of the recipe, maximum caloric intake of the recipe). The system shows this information on the recipe screen and uses it to adapt recipes.

After identifying the user, the remote screen gives instructions on how the system works. For example: *put your ingredients and the ideas cube on the tabletop to obtain appropriate recipes*. When an ingredient or a tangible object (in our software architecture) is detected, it is automatically associated with a tangible agent through an exchange of information between the layers (hardware and middleware). This agent will have a set of knowledge on the type of product, its position on the tabletop surface and the expiration date.



(a) Placing ingredients on the tabletop (five in this case) (b) Looking for ideas with the *Ideas Cube* (a dessert)

Fig. 5. *Cooking ideas* on Interactive Tabletop

After placing ingredients on the table surface, users can use an object to trigger actions. This tangible object, called the *Ideas Cube*, searches for and displays recipes on a screen. The sides of this object determine whether dish or dessert ideas will be displayed. The agent in charge of the *Ideas Cube* communicates with other agents, such as *ingredients*, to collect data and sort the recipes in a database by relevance. When the user changes the face of the *Ideas Cube*, other recipes adapted to the characteristics of the user card are displayed.

When a recipe is selected, the agent transfers the information to the upper layer (the HCI layer). The HCI layer is responsible for user feedback. Initial user feedback is shown on a LED display on the interactive table. These LEDs are used to highlight the ingredients in two ways:

- With a halo below objects. The halo may be: (1) green: represents a necessary ingredient in the recipe; (2) red: represents an unnecessary ingredient in the recipe; (3) orange: the *ideas cube* is not on the table (e.g., no recipe is selected).
- With a connection between the ingredients used in the recipe.

Secondary user feedback is provided on a screen. This screen displays useful information for making the recipe (e.g., description, preparation time, cooking time, popular recipes, price) and the list of ingredients and their quantity/weight. If some ingredients are missing on the interactive table, the application notifies the user.

5. Technical and user-centered evaluations

5.1. Technical evaluation

In section 5, we present two complementary evaluations of the *Cooking Ideas* application. The first technical evaluation is focused on a study of digital data about the MAS related to events. These events illustrated in Fig. 5(a) are trigged by use of different types of objects. The table 1 presents events like the use of ingredients on tabletop. During an event at a time T_i, digital information is given on the number of objects detected by the tabletop, the sum of agents and the number of exchanged messages between agents. For example, when a user puts the "Ideas Cube" after placing $n = 5$ ingredients, the system contains 7 Tangible Agents (TA) and 7 Virtual Agents (VA) for the located display (VA-located: 5 ingredients, 1 user card, 1 *Ideas Cube*). To display a recipe on the screen, 21 ACL messages of *request* or *inform* types are exchanged between agents; their number depends on the number of ingredients (called n), $4n + 1$.

Table 1. Number of agents and messages during the use of *Cooking Ideas* application

Events	T_i	$\sum TO_i$	$\sum TA_i$	$\sum$ VA-located$_i$	$\sum$VA-remote$_i$	Nb of messages$_i$
User card on tabletop	0	1	1	1	1	2
User card out of tabletop	1	0	1	1	1	2
n ingredient(s) on tabletop	2	n	$1 + n$	$1 + n$	1	0
Ideas Cube on tabletop	3	$1 + n$	$2 + n$	$2 + n$	2	$4n + 1$

Such linear function is obtained thanks to the design choices concerning the software architecture (presented previously in section 3) decomposing clearly the types of usable objects.

5.2. User-centered evaluation

An evaluation has been conducted with 20 participants during one week to validate this new interaction system. The overall goal of the evaluation is to assess the user-friendliness and the perceived quality of use of this distributed user interface. For example, users can add a tangible object to an interactive tabletop while simultaneously being able to see the textual and graphical feedback on a vertical screen in their sight. Each subject was asked to answer the well known SUMI[26] questionnaire related to the use of the distributed user interface. This questionnaire is composed of five subscales. The complete evaluation was not detailed by lack of space. The various scores obtained were fairly high. They were all above 50, which represents the acceptance criteria. The global score was 57,8 which indicates that the system is basically usable according to the survey. This score represents the quality of use of the distributed user interface tested by the subjects. User interfaces with multiple displays can largely improve interaction because they combine heterogeneous display surfaces so that users can take advantage of certain displays for a specific subtask.

6. Conclusion

Interactive tabletop for the manipulation of tangible objects opens new perspectives for applications such Cooking assistant for ambient computing in kitchen. In this paper we described a new type of interactive application, called *Cooking ideas*, distributed on an interactive table and a screen. The application uses an interactive table equipped with RFID technology which allows the detection of real tagged ingredients. We intend to extend our work by upgrade the *Cooking Ideas* concept application by using the classification concept. We aim to classify food (for example with ontology) by semantic similarity (e.g. pasta is similar to spaghetti that is similar to noodle, etc.) or dissimilarity to improve the recipe search algorithm based on ingredients. Furthermore, the recipe could be updated by RSS stream from cooking websites. In a third time, we propose to exploit other surfaces like smartphones or tablets to adapt the application in a remote way.

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