The Physical User Interface Profile (PUIP): Modelling Mobile Interactions with the Real World

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ABSTRACT

So far the field of model based user interface development has focused mostly on the usage of one device, such as a Personal Computer, by one person. New interaction techniques emerge in which the user interacts with the surrounding world while using the mobile phone as a mediator for physical interactions and as communication tool to interact with services and other users. Here several devices or physical elements are used for input and output, and more then one user might be involved. These new settings require description models to support the analysis, design and implementation of systems that take such interaction techniques into account. We present the new UML 2.0 Physical User Interface Profile (PUIP) that is based on the UML 2.0 Profile for Context-Sensitive User Interface (CUP, [11] to support the modelling of this kind of interactions. We show the feasibility of our approach through the modelling of an existing physical mobile interaction and discuss its suitability.

Author Keywords

Physical mobile interaction, interface, modelling, UML 2.0 profile, physical user interface profile.

ACM Classification Keywords

H.5.2 [Interfaces and Presentation]: User Interfaces - Interaction styles; D.2.2 [Software Engineering]: Design Tools and Techniques - User interfaces

INTRODUCTION

Mobile technology has enabled the use of computing in a larger set of contexts, in terms of space and time. Furthermore it has supported the communication among users across different locations and timeframes in a much broader way than traditional telecommunication and computing technologies had done in the past. In this perspective new interaction scenarios emerge, which ask for the design of new interaction techniques and interfaces. In this paper we focus on the issue to define a user interface description that supports the design and development of such interaction techniques. In particular we concentrate on what we call *physical mobile interactions* and on the specific modelling challenges that such interactions imply. We then experiment the use of the UML 2.0 Profile for Context-Sensitive User Interfaces (CUP, [11]) modelling approach, extending it to the new UML 2.0 Physical User Interface Profile (PUIP) and discuss the suitability of this approach for the specified goals.

MOTIVATION

The generation and use of user interface descriptions in general finds its justification in the need to identify and communicate patterns that simplify the complexity of phenomena and support people in discerning meaning. The need to understand complexity makes it vital to think visually and systematically [24]: furthermore, visual thinking supports the communication of abstract ideas. This is the main motivation for graphical models, which enable people to see systems as whole entities, evince relationships among elements, and recognize patterns. Different graphical languages have been developed within different fields (e.g. electronics, mechanics, mathematics) to support the expression and communication of abstract concepts. Within software design there are several examples of graphical system representations: some important modelling issues remain unsolved though, that prevent universally adopting user interface descriptions.

The emergence of physical mobile interaction techniques augments the complexity of interaction phenomena to be modelled. With *physical mobile interaction* we mean any communication between a user, the mobile device, and the physical objects in the real world. Hereby the physical objects can include a computer or not. A possible scenario is for instance a person pointing a mobile device with an embedded camera at a marker on a physical poster. Another scenario could be a Bluetooth interaction between a mobile device and a public digital display. Both of these scenarios can be described as physical mobile interactions.

Physical mobile interaction techniques have raised interest and research effort in industry and academia. This research field deals for instance with "sensing the environment to get awareness of the context of the user" [16, 17], "mobile interaction with enhanced real world objects" [14, 15, 18], "mobile interaction with displays" [19, 20], "mobile annotations" [21] or "using the mobile device as a universal remote control" [22].

Another consideration that motivates our research is that the HCI community, especially within mobile and ubiquitous computing scenarios, has been engaging more interdisciplinary teams lately. Bringing computing out of the traditional location constraints of situated, individual interaction with the personal PC has widened the spectrum of stakeholders engaged in the design and development of new interactive products. Product and interaction designers, service providers, hardware manufacturers, marketing and sociology experts, ethnographers are just some of the professional profiles that assume new roles and relevance in the team. This requires suitable communication tools in order to foster understanding among stakeholders and provide the possibility to contribute to the design of the system from different perspectives.

These are some of the aspects that have driven our research: the next section presents our research and design goals in more detail.

Design Goals

While searching for an appropriate representation model for innovative, physical mobile interaction techniques we focus on the following goals:

- **Support classification and comparison of the existing interaction techniques.** We currently assist to a growing interest in physical mobile interactions, both in industry and research, which leads to new interaction techniques and corresponding prototypes. Therefore a user interface description technique is needed to classify and compare them.
- **Support evaluation of interaction techniques.** The user interface description should support the evaluation of existing and new physical mobile interactions. For instance the number and kind of physical interactions (e.g. move, focus, touch, etc.) and of the involved information displays are important criteria for the usability and complexity of the user interface: such aspects should be presented and detectable in the model.
- **Support all phases of the development process.** Interactions are relevant in every phase of a mobile system development process, which typically consists of analysis, design, implementation, test and maintenance: the description of the interfaces should support all of them directly or indirectly.
- **Support communication between stakeholders.** The user interface description should support the communication between the persons that are involved in the development process such as the software engineer, user interface designer, costumer, analyst, programmer and tester. Therefore an important requirement for the interface description is understandability.
- **Adopt a description which is oriented or based on standards / Tool support.** The user interface description should be based on a widespread and matured standard because this supports its acceptance. Furthermore there is a high probability that existing tools of this standard can be used for the new user interface description.

Specific Issues of Physical Mobile Interaction

Physical mobile interaction techniques raise new issues in terms of modelling in comparison to traditional desktop-based human-computer interaction, due to the augmented complexity of the context. In particular:

- **The physical constraints:** The user interface description should be able to integrate the physical aspects of mobile interactions with the real world. Examples therefore are that the user must be in a specific distance to a physical object before starting the interaction, or that the mobile device touches another object.
- **The device features:** e.g. different screen sizes; different modalities of interaction supported. Most existing physical mobile interactions are multimodal because they use several communication channels. Therefore the interface description should integrate this aspect.
- **The temporal context:** e.g. simultaneous vs. asynchronous presence of multiple users in front of an interactive display; duration of interaction between a user and a display.
- **The social context:** e.g. presence of multiple users in front of a display, wireless user-user communication via mobile devices.

In the next section we look at related work in order to assess whether and how these issues are covered by existing methods.

RELATED WORK

A core state-of-the-art technique for communication, planning and design of software systems is object-oriented modelling. The *Unified Modeling Language* (*UML*) [3] is the current de-facto standard for this purpose being widely accepted in industry and supported by an extensive number of tools. The current version, UML 2.0, provides 13 different diagram types to describe the static structure and the behaviour of software systems. The UML 2.0 focuses more on technical properties of the system, whereas task and user interface modelling is not well supported. However, the UML 2.0 provides built-in mechanisms which can be used to extend the language for this purpose.

On the other hand, during the 1990's a number of languages for user interface modelling were developed [4]. A substantial goal of them was to build a bridge between the UI designer's and the software engineer's perspective on the UI (for details see, e.g., [5]). Usually they base on a *task model* (e.g. *ConcurTaskTrees* [6]) provided by the UI designer and an application model (e.g. UML class diagrams) from the software developer. Both models are used to derive an *abstract presentation model* – describing the structure of the UI in abstract terms – and a *dialog model* which covers the UI behaviour. The last step in the UI development process is the *concrete presentation model*, which is often derived (semi-)automatically from the foregoing models. Since late 1990's several approaches propose extensions for the UML to integrate UI modelling, e.g. *UMLi* [7] or the *UML Profile for Interaction* [8].

Today there is a growing demand for approaches integrating additional and complex requirements of current advanced UIs, e.g. integration of media objects, multimodality, context-awareness, or physical interaction. While for some of them proposals are available (e.g. [9], [10], [11]) there is currently a lack of an adequate modelling approach for physical mobile interaction. One contribution comes from the strongly related domain of augmented reality applications: *ASUR++* [12, 13] also focuses on the modelling of physical mobile interactions. This notation is not based on an existing modelling language like UML and therefore probably neither tool support nor a big community which is familiar with the syntax exists.

In this paper we aim to model physical mobile interactions based on existing and UML-related approaches. Therefore we use the *UML Profile for Context-Sensitive User Interfaces* (*CUP*, [11]), an approach based on UMLi for modelling context-sensitive UIs. CUP is defined as a UML 2.0 Profile, i.e. it uses the built-in extension mechanisms of UML 2.0. Besides, CUP proposes some improvements on UMLi and also updates to UML 2.0 (while UMLi is based on UML 1.4). The most important extension mechanism of UML 2.0 is the *Stereotype*. A Stereotype (notated in «») extends and adapts an existing model element for a specific purpose. It can add additional properties as well as a customized graphic notation. Further details about CUP are given within this paper (where required) in the description of our concrete example.

PHYSICAL USER INTERFACE PROFILE (PUIP)

Our comparison of existing approaches lead to the result that CUP is the most suitable existing approach for our goals: on the one hand it is based on UML 2.0 and considers the results of earlier UML-based approaches; on the other hand it supports modelling context, which can be used for describing the context of use of physical mobile interactions. In the following paragraph we show a complete example of how to model physical mobile interactions based on CUP. Thereby we discuss our decisions on how to apply the given modelling constructs. It turns out that CUP is a helpful and powerful base for context modelling. However, for some aspects additional extensions or adaptations of CUP are required. Thus, we propose a new Profile based on CUP, called *PUIP* (*Physical User Interface Profile*) which encloses CUP elements and necessary extensions which are required specifically for modelling physical mobile interactions.

The section is structured as follows: we introduce an example for physical mobile interaction. We use the example to discuss the CUP diagrams: abstract presentation, context model, and task/dialog model. We extend each model with extensions for physical mobile interaction modelling where necessary.

Example: Physical Browsing

One of the first projects which presented the physical browsing interaction technique was Cooltown [14] from Hewlett-Packard Laboratories. In this interaction technique everyday physical objects like advertisement posters, printers or sights are enhanced by electronic or visual markers that represent a service which is related to the physical object. The user can *click* on these markers with her mobile device and the handheld starts the corresponding service. In this paper we will model physical browsing which takes visual markers and mobile devices with cameras into account. Here real world objects are enhanced by a visual marker comparable to a barcode which represents a related mobile service. The user has a mobile device with an integrated camera and a preinstalled program interpreting the barcode. After the user got aware of a visual marker (e.g. on an advertisement poster) she has to approach it. Then she has to focus the camera of the mobile device on the marker, the marker is interpreted and a webpage related to the advertisement poster is shown on the mobile device. An overview of prototypes and products which are based on this approach can be found in [15].

Figure 1. Physical Browsing.

The previous figure 1 shows the moment in which the focus of the camera of the mobile phone is focused on the visual marker on an advertisement poster.

Modelling Presentation

The presentation model in CUP presents the user interface in terms of abstract user interface elements. It describes the user interface in a platform- and modality-independent way. In a later development step, the concrete user interface presentation is derived from the abstract presentation model. The concrete presentation realizes the abstract elements (e.g. using a standard widget toolkit) and specifies additional properties of a concrete user interface implementation, like layout and adornments. Often, the concrete presentation is created directly in user interface building tools, thus we do not mention it further in this paper.

CUP provides four different user interface elements and introduces icons for them. *inputComponent* allows the user to input or edit some data in the system. *outputComponent* presents some information to the user (without possibility of editing). *actionComponent* allows the user to invoke some action of the system (without additional data input). *groupComponent*s are used to structure the other three types of elements (like e.g. a window on a graphical user interface). The following figure 2 depicts the elements *inputComponent*, *outputComponent* and *actionComponent*.

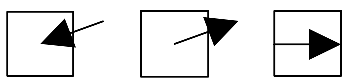

Figure 2. *inputComponent, outputComponent* and *actionComponent.*

The provided model elements are sufficient for physical mobile interaction. However, it must be kept in mind that here they can also be realized by real-world objects in addition to conventional user interface devices.

Figure 4 on the right hand side shows the abstract presentation using the notation provided by CUP. For example the *groupComponent FocusAndBrowse* includes the *outputComponent FocusOfTheCamera* and the *actionComponent StartMarkerInterpretation.*

As mentioned above, an important characteristic of physical mobile interaction is the realization of the user interface elements on different devices or real-world objects. Thus, this should be specified within the presentation model. CUP does not offer a specific modelling construct for this purpose. However, *deployment diagrams* from standard UML 2.0 can be used for this purpose, as they describe where to deploy an artefact of the implementation (e.g. on which device). In our case, deployment diagrams would then map the abstract user interface elements to the different devices. However, the relationship to the device is one of the core characteristics of our user interface elements. In our experiments we found out that it is not suitable to search for this information within a separated diagram. Thus, we introduce a new relationship (extending the UML 2.0 association) *renderedBy*, which connects a group component and element of the context diagram. The following figure 3 shows an example of the introduced association. The *groupComponent InitialDisplay* is *rendered by* a handheld device.

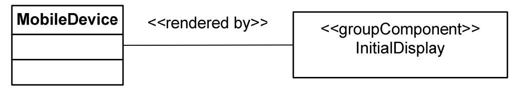

Figure 3. Example for a *rendered by* association.

In our example, there are two different displays involved in the interaction technique “physical browsing”: the display of the mobile device and the advertisement poster (*display*) with the visual marker is also a display. Figure 4 also shows which interface components are rendered by which device. The mobile device presents three different screens during the physical browsing interaction. The display, which is an abstraction of the advertisement poster, is static and therefore presents only one screen during the interaction technique. The classes *MobileDevice* and *Display* are essential elements of the context of use which is modelled afterwards in the context diagram.

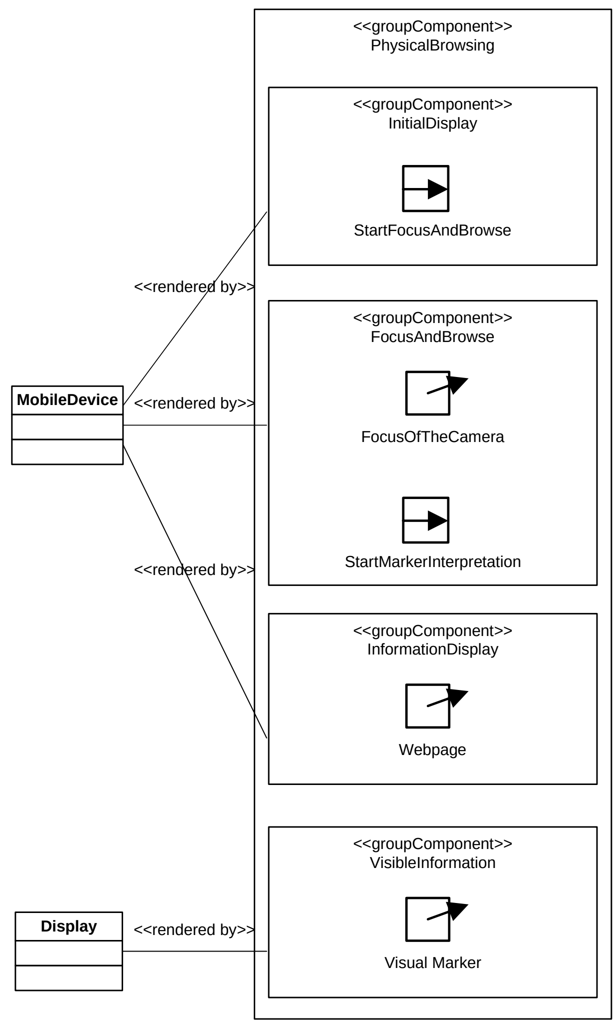

Figure 4. Abstract presentation specification.

Modeling Context

The CUP uses UML 2.0 class and package diagrams for the description which context information is used for the adaptation of the user interface and the application itself.

Furthermore it introduces Stereotypes to consider how the context information is gathered.

In contrast to that we focus on the context of use which is required for this interaction technique. Here we describe which properties the involved entities should have and which physical constraints for the interaction exist. Thereby, the notation provided by CUP is suitable for our purpose.

The following class diagram in figure 5 depicts the generic context that is valid for the whole interaction. The classes *User*, *MobileDevice* and *Display* are introduced which are all special *InteractionElement*s with a corresponding location. The relationship classes *U_MD_Relationship*, *MD_D_Relationship* and *U_D_Relationship* (U = User, MD = Mobile Device, D = Display) express the physical relationships between the interaction elements.

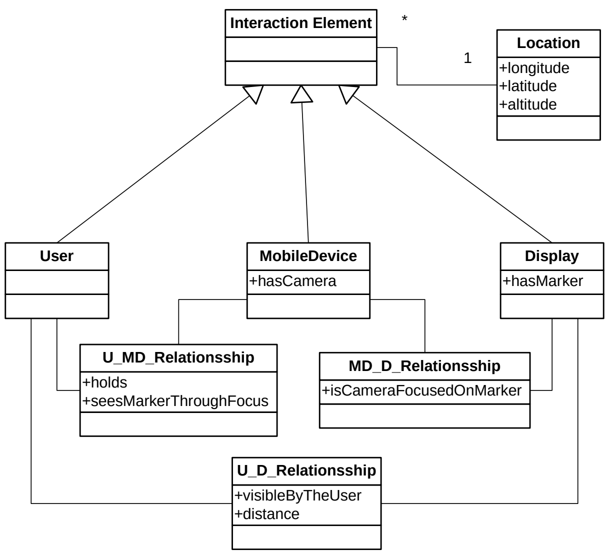

Figure 5. Interaction elements and relationships.

An important aspect is the dynamic change of the concrete context during the interaction. To specify the context for a specific point of time during the interaction we propose to use UML 2.0 object diagrams. Analogous to conventional classes and objects in UML 2.0, a concrete context information at runtime is an instance (i.e. object in the object diagram) of the general context description in the class diagram.

The following figures 6 and 7 depict the concrete context of use before starting the interaction and at the end of the interaction. Both object diagrams state that the

- Mobile Device has a camera (*MobileDevice*),
- Display has a visual marker (*Display*),
- User holds the mobile device (*U_MD_Relationship*) and that the
- Display is visible for the user (*U_D_Relationsship*).

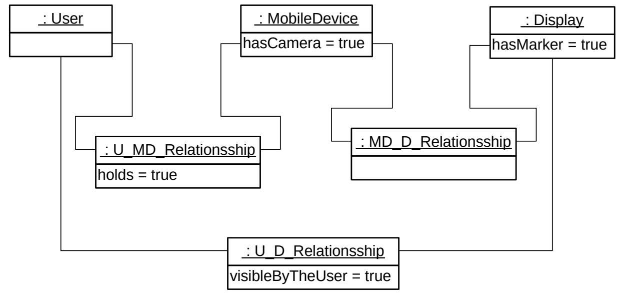

Figure 6. Context of use before the interaction.

At the end of the interaction (figure 7) the user has also a special distance to the display (*U_D_Relationsship*) and the camera of the mobile device is focused on the marker on the display (*MD_D_Relationsship*).

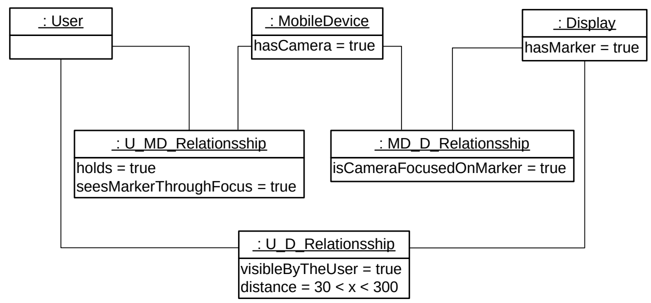

Figure 7. Context of use at the end of the interaction.

Modelling Tasks and Dialogs

CUP uses UML 2.0 activity diagrams to model tasks based on the concepts used in ConcurTaskTrees [6]. Tasks are represented by actions, which are extended by the stereotypes *user*, *system*, and *interaction* to specify user tasks, system tasks, and interaction tasks analogous to [6]. In addition, as they describe context-sensitive applications, they introduce a stereotype *environment* to specify tasks performed by an entity in the physical environment that is neither the system nor the user. Temporal relationships between the tasks are specified using the various modelling constructs provided in standard UML 2.0 activity diagrams.

In our case nearly all actions in the activity model are interactions between the user (*user)*, the mobile devices (*system)* and the physical world (*environment*, *system*) as already mentioned in the introduction. Thus, to achieve more expressive power, we slightly modify the semantic of the stereotypes: we use the stereotypes *user*, *system* and *environment* to describe which entity involved in the interaction *starts* a specific action in the activity model.

Based on the task model represented by the actions in the activity diagram, a dialog model is specified. It shows the relationships of tasks (i.e. UML actions) to abstract user interface elements and to contextual information. CUP uses the standard UML *object flows* as the modelling construct to denote these relationships. Object flows represent the flow of data from or to an action, analogous to input or output parameters of an operation.

We first look at the relationships between user interface elements and actions: they specify that some information is sent to, or gathered from the user interface element. For example in figure 8, the action *StartApplication* depends on the user interface element *StartFocusAndBrowse*. We found that object flows do not exactly fit to this semantics (why?), and use UML dependencies instead, to express these relationships.

For the user interface elements themselves it is important to see their relationship to a device or physical real world object. As explained above, the presentation model specifies these relationships. Thus, one has to refer to the presentation model to find out which device or real world object is related to an action (as the action is related with user interface elements). To achieve better usable models, we propose that it is optionally possible to annotate the instances of user interface elements in the dialog model with a textual value showing the related device or real-world object. In the same way, user interface elements can be annotated with the name of the group component they belong to. We propose a notation similar to attribute values below the icon of the user interface element (as part of the customized graphical representation of the Stereotypes *inputComponent*, *outputComponent*, and *action-Component*). In figure 8, e.g., the user interface element *StartFocusAndBrowse* is annotated with property values showing that the element is part of the group component *InitialDisplay* and rendered by the device *MobileDevice*.

CUP uses relationships between actions and context collectors, to show which contextual information is involved within the action. However, as described above, it is important for our purposes to specify the contextual situation required for an action within the physical mobile interaction. As introduced with the contextual model, we use context objects to describe a concrete runtime instance of context information. These constructs also fit well for our purpose here: we use context objects to describe the required concrete context instance, required for an action. We introduce a stereotype *requires* which represents a dependency between an action and a context object with the

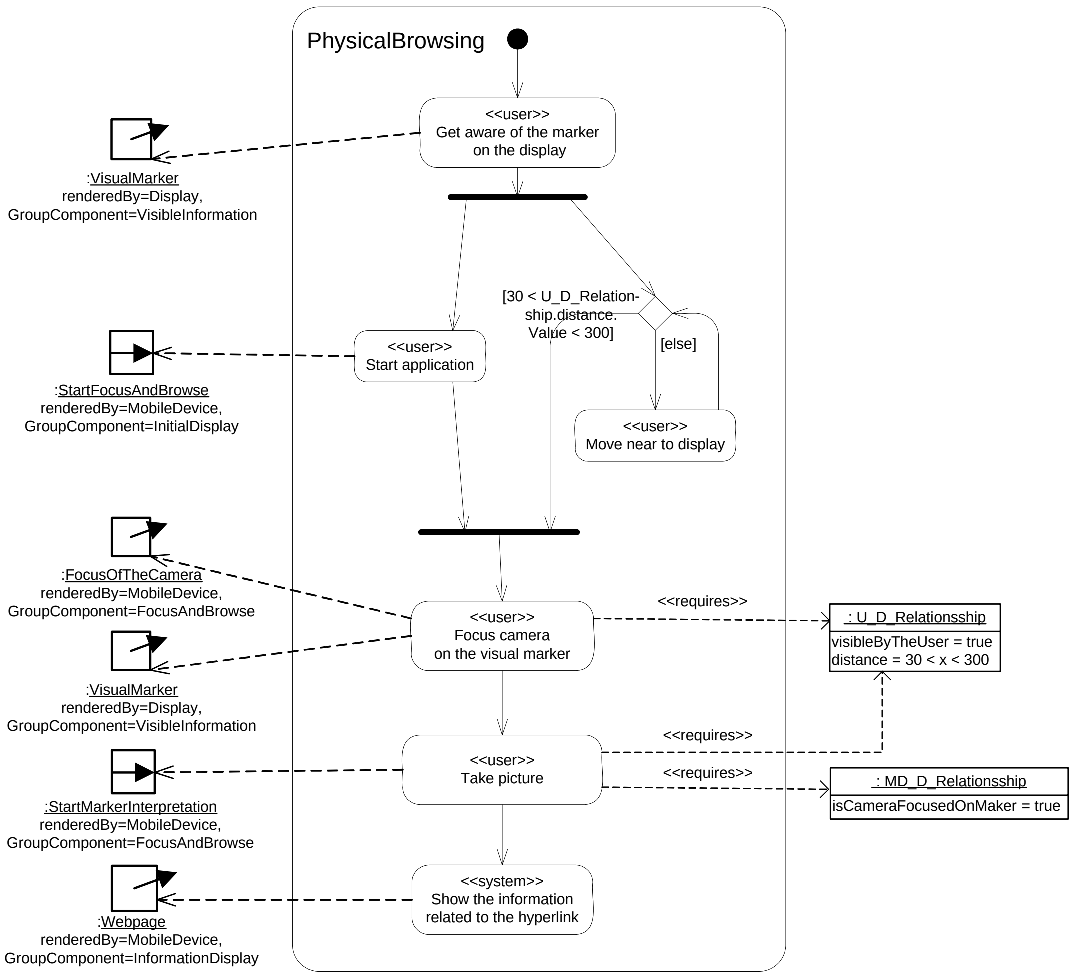

Figure 8. Dialog Model „Physical Browsing“.

meaning that this context is required to execute the action. For example in figure 8, the action *Focus camera on the visual marker* requires that the user sees the device and is in an appropriate distance to the display. This is specified by the values of *U_D_Relationship*.

In addition, conventional UML guards can be used to express constraints on control flows, like *30 < U_D_Relationship.distance.value < 300* in figure 8.

In the following we explain the complete interaction technique "physical browsing" depicted in figure 8 using the proposed modelling constructs of PIUP. The first action is started by the user («*user*»). At the beginning of the interaction technique the user must get aware of the marker on the display. This interaction of the user and the user interface element *VisualMarker* is depicted by a corresponding UML dependency. Through looking on the abstract presentation specification (figure 4) or the annotation one can find out that *VisualMarker* is part of the *groupComponent VisibleInformation* which is rendered by a display (e.g. an advertisement poster). The interaction is done without using the software of the system: it is exclusively a cognitive and physical action. This first interaction is very important for the interaction technique "physical browsing". In this way, a person who reads this specification knows that there should be a visual attraction on the display, which calls the attention of a potential user. In this sense not only the design of the software and hardware components are important for the development of such a system. The specification of the physical environment, in this case the design of the display, plays an important role for the usability and acceptance of such an interaction technique.

In the next step the user can execute two actions in parallel: start the application *FocusAndBrowse* on the mobile device and approach the display. The latter action is essential for the interaction because the marker must have a specific size in the image taken by the camera of the mobile device. Therefore the user and her mobile device must be in a distance of 30 to 300 centimetres. Through this a physical constraint is expressed which is essential for the usage and evaluation of the interaction technique. If for instance someone plans to use this interaction technique in an airport where a lot of posters are attached to high walls then this kind of physical browsing is not feasible because the user is not able to go close enough.

The next action is again triggered by the user after the two previous actions were performed. Here the user has to focus the camera of the mobile device on the visual marker of the display. This is a typical example of modelling a multimodal interaction because the display of the mobile device and another display are involved. This is indirectly depicted by the related user interface components *FocusOfTheCamera* and *VisualMarker*. This interaction fulfils the requirement stated by the object *MD_D_Relationship* on the right hand side of figure 8 which is an important precondition of the following actions.

Afterwards the user has to take a picture of the marker on the display; the system processes this picture and shows the information related to the physical hyperlink on the display of the mobile device.

CONCLUSION / DISCUSSION

In this paper we discussed the issues of modelling physical mobile interaction techniques. By reviewing existing modelling techniques, we validate the suitability of the UML 2.0 Profile for Context-Sensitive User Interface for the interface description. We verify the feasibility of using this method for modelling physical mobile interactions and propose the Physical User Interface Profile (PUIP). This is an extension of the CUP to fit the specific issues raised by physical mobile interactions. The most important differences to CUP can be found in the model of the abstract presentation and the dialog model because PUIP introduces new approaches for the integration the physical and multimodal aspects of the interaction.

While supporting the suitability of such approach as a standardized tool, we reckon its limits in terms of communication tool, which is one of the design goals we stated at the beginning. This consideration arises from direct experience within our research team, which involves interaction designers as well. Even though such a model is relatively easy to understand even for people with limited or no programming skills, the model runs short in performing as real working tool for designers. One of the main constraints appears to be the fact that the model accommodates requirements and functional issues, but provides little insight of how the interface should actually look like. Furthermore the elements that constitute this graphical representation are little diverse and self-explanatory, thus providing only limited support to pattern recognition and visual thinking. Some work has been done in the area of UML to better support visual thinking by colour coding [23]. Possible further extensions of the model might include pictograms of physical actions or pictograms of displays for more immediate recognition of the interaction type and flow: we are aware, however, of the trade-off between the level of abstraction and the detail of context/interaction description.

In the future we aim to validate such models with further physical mobile interaction techniques, which might include haptic and sound displays. In this sense it will be a major issue to represent the modality of the interface, possibly in such a way that it is visually recognizable what kind of input/output modalities are used by the interfaces. Additionally we plan to specify how multiple simultaneous interactions are rendered in terms of user interfaces on different devices, which might be held by different users, interacting on a shared display.

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