Applications of a Modular Interaction Framework for Virtual Reality Testing in a Smart Environment

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Abstract

In the future mobile devices will be used for many different purposes in the Factory of the Future, like displaying user-specific location-aware information about production processes, energy flow and resource consumption. The planning of these challenging future factories requires intuitive interactive virtual testing in an immersive environment prior to the building of the plant. In the EU-funded project uTRUSTit we have developed a Virtual Reality interaction framework designed for testing target group-specific intuitive user interfaces on mobile devices in the Internet of Things. This developed framework also enables us now to carry out interactive VR application scenarios in the context of the Factory of the Future. In this paper we will describe the requirements and developed functionalities of our framework. We will outline how the framework design and implementation can be adapted, using two exemplary Factory of the Future scenarios; first as an interaction device in an immersive environment for pre-building verification in industrial plant construction it supports extended toolsets; second as an immersive usability test environment that allows testing the reaction of user groups to interface elements depending on location and reaction.

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1. Introduction

The Factory of the Future (FoF) will be an industrial Internet of Things (IoT) with many different smart devices connected internally and externally via internet. Especially because of the higher number of devices and the enormous amount of available information and interaction possibilities, it is necessary to develop and install easy to use devices. Those devices have to provide the relevant information for a certain application at a specific time for a unique user. In addition interaction applications have to be intuitive and trustworthy.

In this paper we will discuss how the results of the EU funded project uTRUSTit (usable Trust in the Internet of Things) regarding suitable user interfaces, interaction devices and informed trust decision can be adopted for the FoF.

2. uTRUSTit

The EU-funded project uTRUSTit (http://www.utrustit.eu) aims to develop and implement guidelines and tools to build and test trust in the IoT. One main objective is to implement a trust feedback toolkit. Therefore user requirements on trust in the IoT and cognitive mental models of user trust perception had to be developed [1]. In addition guidelines on the creation of usable interfaces have to be brought up. With all this tools and guidelines uTRUSTit wants to provide trust and security related information about different devices in the IoT in an usable way. This will help the users of the IoT to make informed trust decisions on using or even not using certain devices and services in the IoT.

uTRUSTit has a specifically user centered design approach. Therefore it was very important to get
feedback of potential end users at a very early stage in the project. In that stage of the development phase, no functioning prototypes of the devices were available for testing. So the Virtual Reality (VR) Technology was chosen to be used for early user testing within the uTRUSTit project. Using VR we were able to get end user feedback at a stage in the project when no physical prototypes were available. The results of the first round of the VR user tests were than used to improve the real-world prototypes. So the VR environment was used to simulate and visualize two previously defined test scenarios “Smart Home” and “Smart Office” (Fig. 1) including the interaction with the smart devices and the provided trust feedback.

Therefore we aimed to develop a generic framework that eases the implementation of VR user tests with different interaction and navigation devices and methods by providing flexible tools for hand-free navigation in VR and interaction with the virtual objects.

3. User Testing in Virtual Reality

In the two scenario which were chosen to be tested in VR – Smart Home and Smart Office – the real world smart devices where smart phones and tablet computers. Consequently the VR interaction devices also had to be a smart phone and a tablet computer that simulate the interaction with the IoT (Fig. 2).

During the user tests the participants had to solve different tasks within the office and the apartment of the future. The interaction device for the Smart Office scenario was a smart phone, the tablet computer was used for the Smart Home environment. During the user tests, both, the interaction with the virtual environment (e.g. opening doors, buying different items) and the displaying and evaluation of different user interfaces providing feedback about trust level and security status of the IoT-connection, were needed. Therefore a modular framework had to be developed (see Chapter 3.1). In contrast to [2] our framework does not use Interaction Modules as middleware but takes advantage of the existing possibilities of the VR system and connects them to the user interfaces on a real device.

Usually the navigation through a virtual environment is realized using a handheld device like a flystick or a space mouse [3]. In testing scenarios, were the interaction devices should simulate user interfaces (e.g. an operator panel in a factory) or specific devices (machine operation panel) a handheld navigation device is difficult to use or even not usable at all. Therefore a
hands-free navigation method had to be developed. In addition this method should allow the test participants to explore the virtual environment in a natural way as possible. There are different hands-free navigation methods available, some, like using a treadmill [4] or a walking pad [5], already used for navigating in virtual environments, others like the Wii Balance Board or the Microsoft Kinect well known from gaming. For the first round of uTRUSTit VR user tests the Wii Balance Board was chosen as navigation device (see Chapter 3.2).

3.1. Modular Virtual Reality Interaction Framework

The interaction between the Android device and the VR scenario is bi-directional and event driven. Users can manipulate objects at a random point in time in the VR scenario and a change in the VR scenario can trigger a reaction from the user. Therefore the communication between the Android device and the VR scenario had to be designed in a way that the Android device can send information to the VR scenario (running inside the VR software system) to execute the manipulations. Additionally it has to be possible for the VR software to send information about changes in the VR scenario to the Android device. Therefore an event driven software system for the User-to-VR-scenario interaction was designed and implemented.

The Android VR system interaction framework consists of two modules. The first, named VR Event Manipulator (VREM), is responsible for executing manipulations and for notifying about changes in the VR scenario. The second module is a framework that allows scripting event driven Android applications for the VR interaction scenarios. It is named Builder for Event Driven Interaction Scenarios (BEDIS). Both interaction components are displayed in Fig. 3.

![Fig. 3 VR interaction components](image)

The manipulation of VR scenarios involves three components. First the VR software system that runs the VR scenario which has to provide an API for manipulating the scene graph of the VR scenario while running. The second component is the developed VREM that uses the API of the VR software system to manipulate the VR scenario and retrieve information. Further the VREM also provides an interface for executing the VR scenario manipulations and for getting information about node properties of the VR model. The third component is an abstract VREM Interactor that implements the interface of the VREM so it can be notified about VR model properties and trigger manipulations. For the described project a specific VREM Interactor implementation was done as an Android app using BEDIS (Fig. 4).

![Fig. 4 The design of the VREM and the way of manipulating the VR scenario](image)

As shown in Fig. 4, the VREM module consists of two components. The core module, the VR manipulation event system, provides the high-level interaction access to the VR software system. It is realized as an Event-Action-Condition-System which allows the definition of complex VR scenario interaction. The other component, the VREM Player, controls the execution of these scenarios and also the interface for the VREM Interactor (Fig. 4).

BEDIS was developed to design and implement a framework that can be used to script an event driven Android application which can interact with the VR scenario by representing an implementation of a VREM Interactor (Fig. 4). The core of BEDIS is a state machine [6] like Action-Guard-NotificationEvent-System that uses of the observer pattern [7].

In this system an Action represents an action of the Android device like changing the screen content, playing a sound, vibrating or triggering a VREM-Event that is executed when the Action is activated. It determines its activation by observing the Guards it is listening to. By listening to the same Guards it is possible to activate multiple Actions at once, like changing the screen content on the Android device and playing a sound on it.

A Guard wraps a Boolean value and notifies its listeners when its state has changed. The state changing of the Guard depends on NotificationEvents that are sent to the listening Guards.

Currently NotificationEvents are sent by GUI controls like buttons and through changes of node properties in the VR-Model sent by the VREM Player.

3.2. Navigation

As stated before, hands-free navigation had to be used as the interaction devices were handheld. Therefore the Wii Balance Board was chosen to navigate through the virtual environment. It is a robust, cheap product and provides easy access by using existing programming libraries. The Wii Balance Board has four pressure
sensors, one at each corner. The data is transmitted through a Bluetooth connection to the host device.

A couple of different research teams already used the Wii Balance Board for navigation tasks in VR. De Hann et al. [8] inspected the possibilities of using the Wii Balance Board as a navigation device in VR and described different metaphors for triggering movements. Hilsendege et al. [9] used the Wii Balance Board for navigation through a previously created virtual BioSphere. They found out, that sigmoid functions serve best as transfer functions for rotation and acceleration and confirmed this by an explorative pre-study. Fikkert et al. [10] compared the ease of using a Wii Balance Board to a Wiimote handheld control.

Fig. 5 shows the Wii Balance Board System Setup for realizing the navigation in the described user evaluations. The Wii Balance Board is connected to a computer using the standard Bluetooth connection.

An application has been developed that uses the aforementioned Wiimote Library for reading the values from the Balance Board and calculates the vectors for translation and rotation of the user’s viewpoint. The application sends the calculated vectors to the VR system where it is transformed into user movement. The sensors detect the pressure the user exerts on them by shifting his or her weight sideward and back and forth. To derive a movement vector from the sensor’s values, the balances between back and front and left and right are mapped to values between -1 and 1 for both directional balances as described in [9]. To get as close to natural movements as possible, the back to front balance is used to control the speed and the right to left balance for controlling the direction the user moves in the virtual environment. To translate these into movements in VR they are multiplied with different transfer functions, derived from pre-tests. For standing still, these functions contain an interval where the resulting value is zero, so the users can interact with their devices without paying too much attention to his/her weight balance.

4. Factory of the Future applications

The success of the Factory of the Future concept will highly depend on the usability of the interfaces and used smart devices leading to acceptance or refusal in those people who are supposed to work with them. Therefore it is most important to develop those concepts and interaction devices with a user centered design approach, which includes end user tests at an early stage in the design process. The described software framework enables companies and users to control a virtual environment using interfaces on mobile devices. It therefore enables basically two different ways of VR based testing.

4.1. Prebuilding Verification

Factory planning is very often supported by the extensive use of 3D graphics, for example in [12] the coupling of a 2D planning application with a VR viewer is described.

Using the software framework for prebuilding verification allows applying a smartphone or tablet PC as an enhanced interaction device in a virtual environment. Using the interfaces on the device the future factory could be changed while standing inside the virtual world. Machines or shops could be moved, their parameters adjusted and additional information e.g. about the transport routes and distances could form an additional layer of information.

In addition to the adjustment of the factory layout, the described VR based test setup allows the designer of the smart control devices enhancing the FoF concept to test their usability, applicability and integration in the whole FoF concept using a scale 1-to-1 model of the factory interacting with its components as it will be in the real factory.

For testing different smart interfaces and devices in one test setup, the framework allows for adding location awareness to the apps behavior, so dependent on one’s position in the VR environment just the reasonable options could be shown on the display.

4.2. Immersive Usability Test Environment

Apps for manufacturing purposes have to be well crafted, easy to understand and operated. To assure this, interface testing with different end user groups in a virtual environment are an appropriate means [1].

Mobile apps are used in different environments, in the production facility itself but also to access information while abroad. Those smart apps for production (SMAPP) are in use everywhere, mostly on consumer smartphones and tablet PCs. The industry is well aware of the potentials of applications on mobile devices and is
Franziska Pürzel et al. / Procedia CIRP 9 (2013) 35 – 39

39

exploring its benefits [11], so more and more SMAPP are being developed.

To test user reactions in different situations the diverse environments have to be implemented in Virtual Reality. While simulating a production facility the production process would have to be modeled in the virtual world to be accessible. The framework provides the ability to change the surrounding dependent on the user’s actions without requiring the application to be implemented. Through user’s reactions the usability of the application can be determined and improved.

In addition the framework allows determining the test participants position and movement in the simulated environment. That makes it possible to even test applications that support location-awareness by using Near-field communication (NFC) or other technologies. An application that shows machine status and production data in the surrounding of a machine tool could serve as example.

5. Conclusion and Outlook

The first VR user evaluations within uTRUSTit show that the developed software framework in combination with the Wii Balance Board navigation and the interaction devices is suitable to get early user feedback on usability and applicability [13]. Nevertheless, some problem especially with the Balance Board navigation occurred [13] and need to be solved.

Therefore we are currently implementing a Microsoft Kinect based navigation method for the second set of VR based user tests. Parallel to those VR based user evaluation real-world user evaluation will be conducted – VR mirroring reality as much as possible. The results of both evaluations will then be compared.

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