

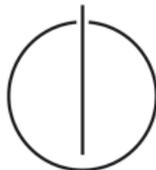
FAKULTÄT FÜR INFORMATIK  
DER TECHNISCHEN UNIVERSITÄT MÜNCHEN

Diplomarbeit in Informatik

**Wartungsunterstützung mit hybriden  
Anzeigesystemen**

**Maintenance support using hybrid  
displays**

Editor: Andreas Demmel  
Supervisor: Prof. Gudrun Klinker, Ph. D.  
Advisor: Dipl.-Inf. Björn Schwerdtfeger  
Submission Date: April 15, 2008



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## *Kurzbeschreibung*

*Da jedes System immer komplexer wird, wird auch die dazugehörige Wartung immer schwieriger. Diese Diplomarbeit beschreibt ein Wartungsunterstützungssystem, das den Wartungsablauf einfacher und weniger fehleranfälliger macht. Im Speziellen wird ein Workflow Editor und die zentrale Runtime Engine für das Wartungsunterstützungssystem erstellt. Dieses System teilt die Informationen physisch in ein where-to-act und ein what-to-to Display auf. Das where-to-act Display liefert einfache Richtungsinformationen direkt auf dem gewünschten Objekt in der Umgebung und wird von einer Laserprojektion dargestellt. Das zusätzliche what-to-do Display gibt dem Benutzer die etwas komplexeren Anweisungen. Schließlich wird das System mit einer Anwendungsanalyse getestet.*

## *Abstract*

*As every system becomes more and more complex, the according maintenance becomes more and more difficult. This diploma thesis describes a maintenance assistant system which simplifies the maintenance action and makes it more fail-safe. In particular, a workflow editor and the runtime engine of the maintenance assistant system are developed. This system divides any information physically into the so-called where-to-act and the what-to-do display. The where-to-act display provides simple directional information directly on the desired object in the environment and is presented by a laser projection. The additional what-to-do display tells the user the complex instruction. In the end, the system is tested with an application analysis.*

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# 1 Introduction

Maintenance is a very important aspect when talking about a product's lifecycle. This thesis describes an AR-based maintenance assistance system which combines two displays to one hybrid display. The hybrid display consists of a so-called *what-to-do* display and a *where-to-act* display. The system supports a mobile maintainer with instructions of the work and directional information at the object. The AR-based maintenance assistance system is adapted to a use case referring to the guided missile system MILAN ADT-ER [1] produced by MBDA Missile Systems [2]. Figure 1 on page 1 shows the MILAN ADT-ER weapon system.

A short introduction to Augmented Reality is presented, and the motives for this thesis will be illustrated in this section. An overview of each section of this thesis is given here, too.



Figure 1: MILAN ADT-ER

## 1.1 Augmented Reality

Many descriptions of Augmented Reality have already been documented by various researchers, so there is no need to write another. A good one is from Gudrun Klinker, in which she describes Augmented Reality in the following way [3]:

”Augmented Reality (AR) is a newly emerging technology by which a user’s view of the real world is augmented with additional information from a computer model. With mobile, wearable computers, users can access information without having to leave their work place. They can manipulate and examine real objects and simultaneously receive additional information about them or the task at hand. Using Augmented Reality technology, the information is presented three-dimensionally integrated into the real world. Exploiting people’s visual and spatial skills to navigate in a three-dimensional world, Augmented Reality thus constitutes a particularly promising new user interface paradigm.”

”Augmented Reality is a new research activity which explores various approaches to augment a user’s view of the real world with additional information. By combining live video input with immersive display technology, Augmented Reality allows users to work with and examine real 3D objects while seeing additional information about the objects or the task at hand. Augmented Reality can be applied in many sectors of industry, e.g., for repairing and maintenance of complex machines and facilities, visualizing sensor or simulation data, and for interior design.”

Figure 2 adopted from [4] shows a picking scenario as an example for an application using Augmented Reality. On the left side the Augmentations when looking through an HMD can be seen. The right side shows a user with an attached HMD performing a picking task.

”Realistic immersion of virtual objects into a real scene requires that the virtual objects behave in physically plausible manners: they occlude or are occluded by other objects, they are not able to move through other objects, and they cast shadows on other objects. Augmented



Figure 2: AR Application for a Picking Scenario

Reality Systems need very detailed descriptions of the real environment to simulate such physical constraints.”

”In Augmented Reality, objects have to be tracked and information has to be rendered in real time. This constraint supersedes all other considerations for pretty and detailed information visualization or user interaction paradigms. In this respect, the chosen approach depends on priorities defined by specific application scenarios.”

## 1.2 Motivation

The MBDA Germany/LFK Lenkflugkörpersysteme GmbH is one of the leading manufacturer for guided missile systems in the world. In addition to MILAN ADT-ER, which was used exemplarily in this thesis, guided missile systems for most possible scenarios are produced, including Medium Extended Air Defense System (MEADS) [5], air-launched cruise missile Taurus KEPD 350 [6] and the PARS 3 LR precision fire-and-forget weapon system [7], to mention just a few.

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For most products, there is hard business competition among companies. So the companies are forced to beat down the prices of their products for keeping up with the competitors. Thus, the selling price of a product is often only at the same level as the cost of production, or even below. This small margin of profit is accepted just to place the product on the market. The actual profit is attained with spare parts, follow-on support and maintenance. These services are used for product life extension or upgrades of the existing product.

The technical logistics section of the MBDA Germany devises maintenance concepts for their products. The intent is to make the maintenance of a complex product as easy as possible to handle and fail-proof. That is why Augmented Reality has found its way into maintenance assisting. A description will follow in section 2 on page 8.

Another important aspect is the training of employees and soldiers respectively. The mission of today's soldiers is not only the national defense anymore, but also foreign assignment. One major preparation for this is good training. Computer assisted instruction is a keyword for modern armies and becomes more and more important in training scenarios, see [8] for further information.

Up to now the usual AR-based maintenance uses Head-Mounted Displays (HMDs) for providing additional maintenance information to the user. Although this is a good approach, it also has some defects, as will be described later in section 3.2 on page 20ff. To optimise the usual approach, an AR-enabling laser-projector type is investigated in this thesis.

In a laser-based approach, a mobile tripod-mounted AR-enabling laser-projector is positioned by the maintainer anywhere in the environment. It is facing towards the object where the maintenance information is needed. In contrast to other AR-applications, the laser-based approach projects the information directly onto the desired object in the environment, so no additional equipment, a display in particular, has to be carried by the maintainer or trainee.

### 1.3 Maintenance Scenario

Due to flexibility of today's armies, a typical maintenance scenario at the armed forces during foreign assignment could take place in a small shelter or tent overseas. For these dynamical situations, it is important to have a very mobile solution. As the calibration of the laser-projector and the camera is done by the system itself, the setup of the environment can differ every time when maintenance has to be done, without engagement of the user.

It is possible during foreign assignment that the proper maintainer is not available for maintenance for different reasons. So with the help of laser-based maintenance another technician, who is not so well-trained on the specific object where the maintenance has to be done, can stand in for the proper maintainer. He is guided through the maintenance workflow and has just to follow the instructions on the what-to-do display and apply them where shown on the where-to-act display.

For further assistance, the maintainer can consult an expert via network. This so-called Remote Maintenance is another important support for the maintainer. The expert can see the image of the tracker camera on his computer display anywhere in the world. He can engage in the workflow and give new or additional instructions and advices of his superior knowledge to the maintainer in real-time. Figure 3 on page 6 shows an illustration of a possible maintenance scenario.

### 1.4 Overview

This diploma thesis can be divided into the following main parts that were necessary to realize the AR maintenance system. The following list gives an overview of each part:

- Section 2 presents related work to this thesis to show what has been developed for Augmented Reality for logistics and maintenance in the last years.
- Section 3 describes the objectives for the AR-based maintenance assistance system. First the concept of the system is defined. Second, the pros and cons

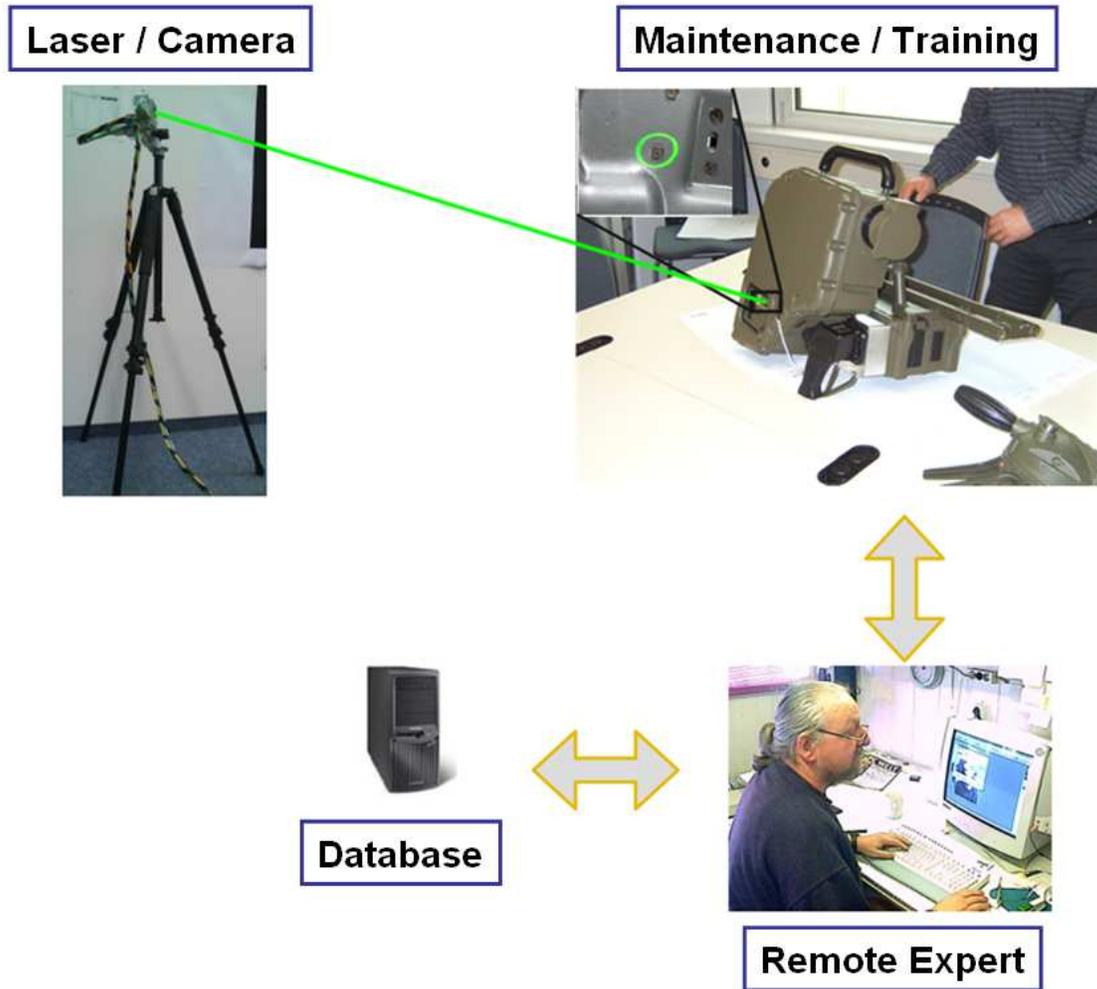


Figure 3: A Possible Maintenance Scenario

of different display types are examined. And finally, the decision criteria for the specific hardware are explained.

- Section 4 shows the resources and tools that were required to develop the maintenance assistance system. Both the hardware components including the laser-projection and camera units, and the software components consisting of

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the UbiTrack Framework and the UbiDisp Framework are presented.

- Section 5 contains the system design. On the one hand, the structure of the WorkFlow which is needed for the maintenance assistance system is described. On the other hand, the single software components of the UbiDisp Framework are explained.
- Section 6 shows a Use Case which was developed for the maintenance assistance system. It includes the installation of the experiment as well as the evaluation of the results.
- Section 7 sums up the results of the preceding sections. Also prospects and possible future work that can be done for upgrading und enhancing the maintenance assistance system are shown.

## 2 Related Work

This section gives a short overview of research and current systems for maintenance supported by AR. Some of them are already using projection displays for presenting additional information.

### 2.1 Projective AR

This thesis arises from the work of Schwerdtfeger et. al. [9] about *Hybrid Information Presentation* with the use of a Head-Mounted Laser Projector (HMLP). In this work, a three dimensional, user centered instruction placement system that supports high quality ubiquitous information presentation for industrial environments is presented. The system uses a hybrid information presentation approach that combines a low resolution three dimensional display done by a laser projector, with a high resolution two dimensional display done by a screen. A portable laser projector to augment a real environment was designed and built into a helmet. The information that is provided by the final system is separated into two aspects: where-to-act and what-to-do. The laser projector displays simple where-to-act information directly in three dimensions on an object in the environment while an additional standard screen provides the more complex what-to-do information. Figure 4 on page 9 adopted from [9] shows the Head-Mounted Laser Projector.

The *Pick and Place Table* is another example for projective AR in industrial applications [10]. Figure 5 on page 10 illustrates the Pick and Place Table. This concept has been established in 1977. The table is used for the assembly of circuit boards. A LED indicates from where the item has to be picked, and a light pointer indicates where the item has to be placed on the table. Further information is provided on an additional screen. One proof that this concept is reliable is shown by the typical error rate which is at only 0.02%.

Another way of providing additional information was examined in the work *Using a Head-Mounted Projective Display in Interactive Augmented Environments* by Hua et. al. [11]. The goal was to project light onto retro-reflective surfaces for generating a 3D view.

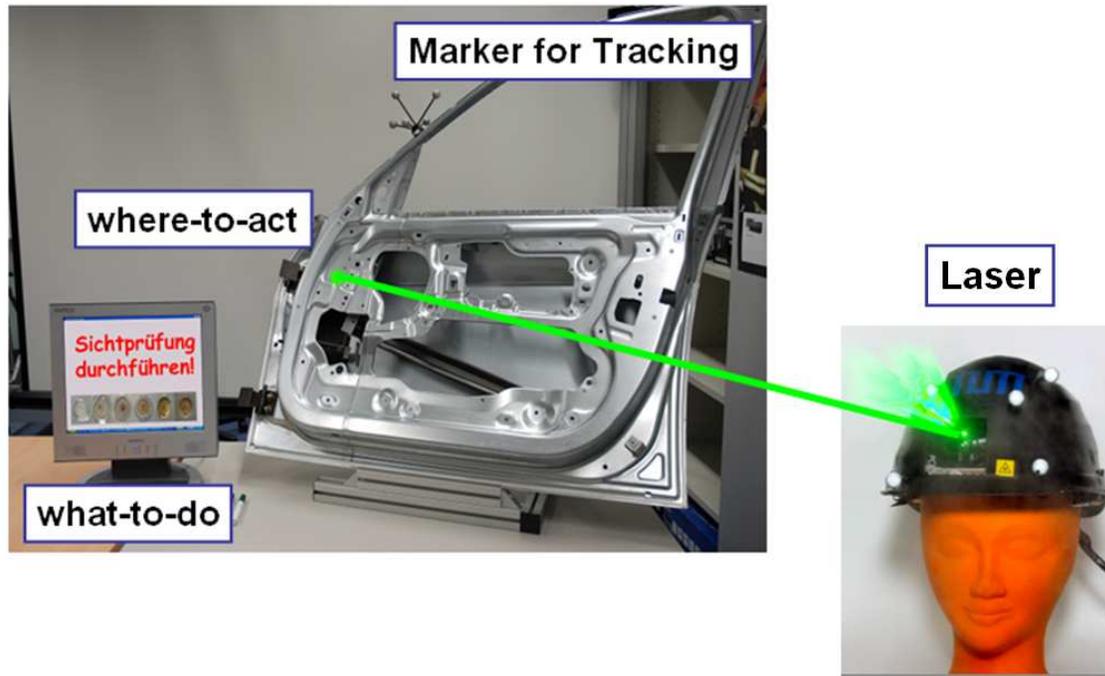


Figure 4: Head-Mounted Laser Projector

The *Wearable Scanning Laser Projector* (WSLP) by Maeda and Ando [12] deals with a laser-projector which is attached on the user's head. This head-mounted projection system uses rapidly scanned lasers to display information directly onto any object, effectively using the surface of the object as a projection screen.

The *Everywhere Displays Projector* by Pinhanez [13] uses an LCD/DLP projector to augment the environment with graphical information. The system uses a rotating mirror to steer the light from the stationary projector onto different surfaces in the environment.

In the work of Bimber et. al. [14] about *Spatial Augmented Reality* conventional projectors that are placed in suitable locations in the environment are used to generate spatial AR scenes. They are able to show seemingly undistorted videos and



Figure 5: Pick and Place Table

graphics on arbitrary surfaces in the environment, due to pre-warping and colour-adjusting the virtual data to counteract the reflection and perspective projection effects of the physical surfaces.

The *Wearable Active Camera/Laser (WACL)* project by Kurata et. al. [15] uses a wearable and remotely controllable combination of a camera and a laser pointer.

A similar approach was developed by Mann [16] with the *Telepointer* project, where a remote user controls a laser pointer that is worn by a user on site, thereby drawing his attention to objects of interest.

## 2.2 Pose Estimation

For markerless tracking respective tracking with natural markers, Ben Himane investigated in the *Vision Targeted CAD Models* project [17] vision features and their

intelligent application on known CAD models for pose estimation. The advantage of combining CAD models and vision features lies in the known 3D geometry of the CAD model. The main goal is to use such an extended CAD model for pose estimation and for tracking initialization.

The *Real-time tracking of complex structures with on-line camera calibration* by Drummond et. al. [18] presents a three-dimensional model-based tracking system. This system combines modern graphical rendering technology with constrained active contour tracking techniques to create wire-frame-snakes and is based on an internal CAD model of the object to be tracked.

The diploma thesis *Markerlose Initialisierung und markerloses Tracking für industrielle Augmented Reality Anwendungen* by Schwerdtfeger [19] deals with the development of a markerless initialiser for a markerless tracking system. This tracking system does not need any external initialisation and meets the requirements of a robust deployment in industrial environments.

## 2.3 AR Maintenance

In the field of industrial applications, two major projects have to be mentioned. The *ARVIKA* project [20] explores AR technologies to support development, manufacturing and service of technical products and facilities. *ARVIKA* was originally developed by the German Federal Ministry for Education and Research, and a consortium of the leading German industry including EADS, Airbus, Siemens, Daimler Chrysler, BMW, Audi and the TUM, to mention just a few. Its follow-up project *ARTESAS* [21] uses the results of *ARVIKA* for tests in industrial environments. The goals of this project are new tracking techniques for rough environments, user-friendly and ergonomic AR equipment as well as the implementation into industrial use cases.

A mobile application using AR is the *ULTRA* project [22]. This project was developed for industrial service and maintenance applications by applying augmented reality techniques to handheld-PCs, a comfortable and unobtrusive

solution.



Figure 6: Augmentations on a PDA Screen

Another work dealing with the *Development of an AR maintenance software based on a PDA client* [23] is about real-time marker tracking and displaying augmentations for a maintenance scenario by Demmel. Figure 6 on page 12 adopted from [23] shows instructions on the PDA screen. This prototype includes also a remote consulting feature, which enables a remote user to see the camera image and to override and change the augmentations and instructions on the PDA screen.

## 2.4 Design of AR-Based Maintenance Systems

In his work *Unterstützung manueller Montage durch Augmented Reality-Technologien* [24] Wiedenmaier describes two main issues how to support manual assembly with Augmented Reality techniques. One of them is the isolation of assembly work and tasks which can be supported by AR. The AR-capability of the assembly work is examined in a study. The evaluation of different assembly tasks in the study is based on a comparison of the needed assembly time, the assembly error and the subjective stress of the user. The other issue deals with the configuration and design of AR-systems used for assembly. The results of this work are scientifically proven guidelines for designing AR-systems.

The work *Einsatz der Computer Augmented Reality in der Instandhaltung: eine alternative gebrauchstaugliche und kostengünstige Systemlösung* by Nikolic [25] deals with the ergonomically design for a usable monitor-based AR-system. A prototype was built with low priced Commercial-off-the-Shelf parts. The suitability of this prototype was examined in user tests. As a result, saving of working time was noticed in contrast to usual paper-instructions, and most users evaluated the AR-based system as positive.

Although a lot of research has already been done in the field of AR-based maintenance assistance, this may be only the tip of the iceberg, of what can be done in the future. The area of applications for AR-based support in industry is almost unlimited.

## **3 Objectives**

This section describes the objectives for the AR-based maintenance assistance system. First, the concept for the best support and assistance for the maintainer will be described. Second, pros and cons of different display types are examined, and third, the decisions and trade-offs that led to this concept are explained.

### **3.1 Concept**

The main purpose of the developed system is an easy to handle and fail-safe assistance system for a maintainer. This section defines both the features and the technical aspects of the concept.

#### **3.1.1 Features**

These features are the result of sustained discussions with engineers of Integrated Logistics Support. The features can be divided into requirements for a stand-alone version, and a version with an expert.

##### **3.1.1.1 Immediate Maintenance**

This concept offers new ways for maintenance and training. If there was only one maintainer who can perform the maintenance on a specific object, but this one is not available at the point when the maintenance has to be done, the maintenance is delayed. But performing the maintenance as soon as possible is necessary, in order to bring the equipment status back to operational again. That is why it may be impossible to wait for the specific maintainer to be ready for duty.

##### **3.1.1.2 Decrease of Training Level**

With a maintenance support like the AR-based maintenance system it is possible to decrease the training level of the maintainer. He does not have to be a specialist on the specific object where the maintenance has to be done. A maintainer with

only basic technical understanding, needs only one instruction on the AR-based maintenance assistance system, and not on every object that has to be maintained. With only one instruction to this assistance system any maintainer can perform the maintenance on various objects. He just has to follow the instructions shown on the hybrid display.

#### **3.1.1.3 Different Instruction Levels**

Different levels of knowledge can afford different levels of instruction. So, a maintainer performing the maintenance act on a specific object for the very first time will require more detailed information on the current workstep, including warnings and hints, than another maintainer who is well-versed in the maintenance workflow. The differentiation of the levels of instruction can be used for another issue, too. If a maintainer had made several mistakes in a short period of time or acts negligently, his level of instruction can be rearranged to be more detailed. A well-versed maintainer may take the augmentations only as a hint or proof of his knowledge about the maintenance workflow.

#### **3.1.1.4 Shorter Training Period**

There are even more advantages for the employer. The maintainer does not need to attend multiple courses to do the necessary maintenance. So the staff training does not take such a long time, and the maintainer is ready for action sooner. Furthermore, the training is less expensive compared to the usual way.

#### **3.1.1.5 Less Service Personnel**

Moreover, with a maintenance assistance system like this, less service personnel needs to be allocated. Currently, for every part of the equipment, there is a particular expert, e.g. an electronics, mechanics and hydraulics engineer, as well as a technician. This over-deployment of personnel is not needed anymore. One maintainer who is instructed in this maintenance assistance system, can do all the work equally.

#### **3.1.1.6 Different Maintenance Levels**

Some parts of the equipment are very sensitive however. So it is obvious, that not an arbitrary maintainer is recommended to perform this specific part of the maintenance action. The installation of different levels of maintenance referring to the complexity of the work can prevent a mal-operation of the system. The first level of maintenance may be the replacement of a battery or the checking of a connection interface, for example. The next level may include the assembly and disassembly of mechanical units and components, whereas the successive level contains also electric and electronic units, etc. This is a balanced proceeding between a fast start of maintenance and reliability.

#### **3.1.1.7 Shared Maintenance Information**

Another desirable concept issue is that not only one user can see the additional maintenance information. With an application that provides sharing of the information, multiple users can use the augmentations on the same hybrid display simultaneously.

#### **3.1.1.8 Remote Support with Superior Knowledge**

Another major goal of the concept is live remote support of the maintainer by an expert via network. The maintainer can call for real assistance by an expert. This so-called remote maintainer has superior knowledge of the equipment where the maintenance has to be done. He may be a service technician or an engineer of the manufacturer. This remote maintainer can obtain his expert knowledge also from a database including more detailed technical information on the equipment where the maintenance has to be done.

#### **3.1.1.9 Data Exchange with Remote Expert**

The remote maintainer can support the local maintainer as good as possible. As an audio communication between the remote and the local maintainer may not be sufficient for the local maintainer, the maintenance support system provides data exchange between both sides. The camera used by the local maintainer for tracking

the environment, delivers its pictures via network to the remote maintainer in real time. So the remote maintainer sees exactly the same, the camera of the local maintainer sees. He can realize the situation and decide accordingly how to support the local maintainer.

#### **3.1.1.10 Telecommanding the Workflow Engine**

The data exchange is bi-directional. The remote maintainer can telecommand the workflow engine. He can send information to the local maintainer, who receives this information on his what-to-do display. This information can either be additional, which appends the remote maintainer's information to the already existing Maintaininfo, or it can be replacing. This means that only the information of the remote maintainer is visible for the local maintainer on the what-to-do display. This feature will be needed if the local maintainer's Maintaininfo is not sufficient or correct, because something has changed in the course of action, and the local maintainer has not updated his information set yet. This information does not have to be only plain text, but can also be an image or video file illustrating the local maintainer's current workstep. A garbled illustration of the maintainer's what-to-do display is shown on Figure 7 on page 18.

#### **3.1.1.11 Override of Worksteps**

The telecommanding of the workflow engine has even more features. If the course of action between one workstep and the following is not clear for the local maintainer, the remote maintainer can add worksteps as a whole, or remove one if this is desired.

#### **3.1.1.12 Override of Augmentations**

To give best support, the remote maintainer can also edit the augmentations. This is useful to show the local maintainer the right location on the object in the environment. Directional information could be given via audio connection, as the remote maintainer can guide the local maintainer because he can see the local maintainer from the viewpoint of the camera. But it is a smarter solution for the

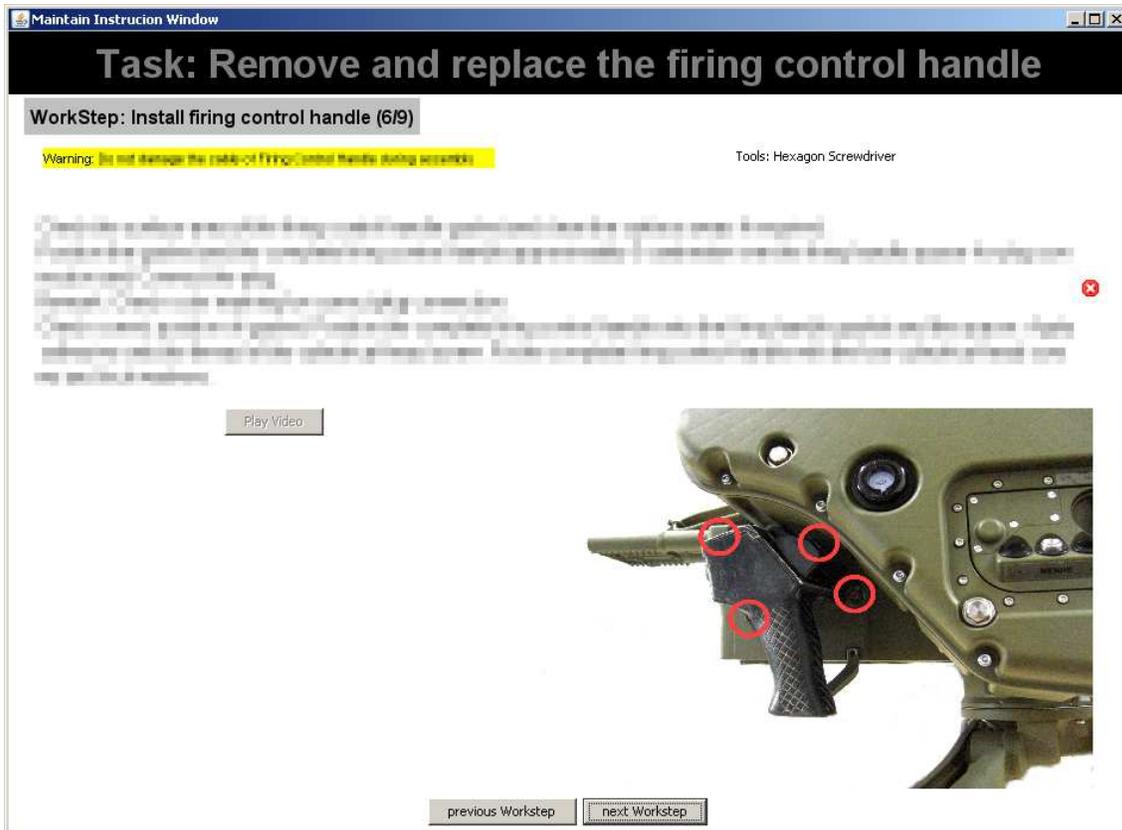


Figure 7: The what-to-do Display

remote maintainer to guide the local maintainer by editing the where-to-act display, that is the laser in this case. Like the Maintaininfo, the editing of the augmentations can also be additional or replacing.

### 3.1.1.13 Worldwide Remote Support

The remote maintainer can be anywhere in the world. He just needs a network connection to this maintenance assistance system. This is useful, if the equipment where the maintenance has to be done is overseas and it is not possible due to temporal reasons to send the equipment to the other side of the world and back just

for maintenance or repair.

#### 3.1.1.14 Remote Training

In another scenario the remote maintainer or expert can sit next door for training a maintainer. The expert does not physically meet the maintainer, but nevertheless he notices every action of the maintainer due to the real-time transmission of the camera images.

### 3.1.2 Technical Aspect

The system is implemented on base of the Simple Component Framework developed by the Chair for Computer Aided Medical Procedures and Augmented Reality (CAMPAR) of TUM [26]. In section 4.4 on page 33 the Simple Component Framework will be explained in more detail. As a component-based system, it is very flexible and modular. The system can run distributed on multiple computers. The single components just need to be connected via network with a TCP/IP connection. Thus, some parts of the system can easily be changed or replaced. Figure 8 on page 20 shows the correlation of the individual components.

One major goal of the concept is to support not only one display type, but different ones. The system is implemented generically, so that different AR-Displays can be connected easily. The characteristics of an hybrid display remains, but there can be different types of where-to-act displays. One possibility is a laser which projects directly onto the surface of the object. But also an HMD worn on the user's head can be used, as well as the stand-alone TabletPC with the augmentation on the LCD-screen.

Furthermore, different tracking methods can be used for the maintenance assistance system, e.g. optical marker-tracking as well as markerless tracking with a CAD model of the object to be tracked. This is possible due to integration of the tracking component into the UbiTrack Framework [27]. Section 4.3 on page 32 will give more detailed information on the UbiTrack Framework.

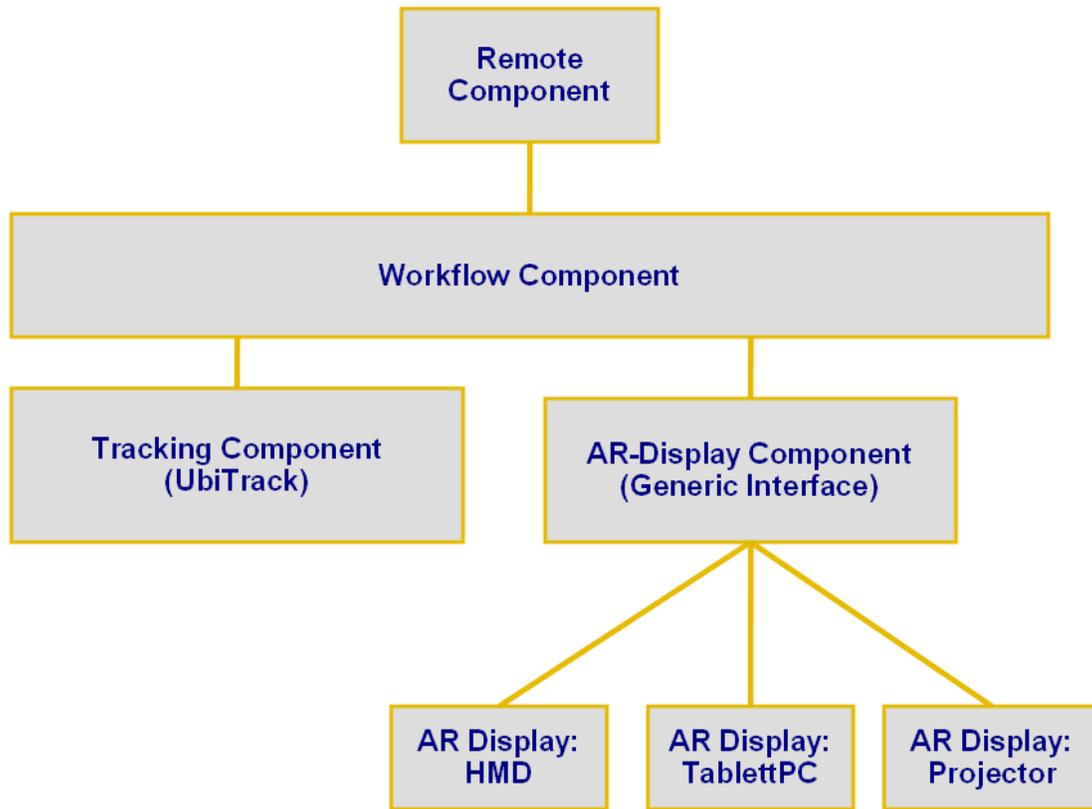


Figure 8: Structure of the Component Based System

## 3.2 AR-Display Types

For the development of an AR-based maintenance assistance system, some display types have to be considered. The pros and cons of different display types are examined in this section. The Display Types here are HMDs, projection displays and TabletPCs.

### 3.2.1 HMD for AR-Based Maintenance

Most of the common AR-based maintenance assistance systems present the additional maintenance information with the help of HMDs which are carried on the

user's head. Though this is a good approach, it also has defects [28].

The main goal of a HMD is to place the images directly in front of the users eyes using one or two small screens. Most HMDs use either LCD or CRT screens. One of the biggest advantages of HMDs is that the user can have a complete physical visual immersion because the user always sees the virtual world regardless of head position and orientation. This can be up to a 360 degree FOR. Many HMDs have a small FOV. Its angle is usually limited to between 30 and 60 degrees, which can result in perception and performance problems. A restricted field of view can impede a user's ability to acquire spatial information, and may also produce distortions in perception of size and distance.

A potential problem with stereoscopic HMDs is that every person has a different distance between his two eyes, meaning that stereo images have to be separated with that distance for correct binocular stereopsis. But many HMDs do not provide a way to adjust this distance making stereo viewing problematic for some users.

Another issue is binocular disparity which refers to the difference between the two images one sees with both eyes. The closer the object is to the viewer, the stronger the binocular disparity carries weight. The fusion of these two images provides a powerful depth cue and is called stereopsis. As the depth cues are linked to binocular disparity they are effective for objects with short distances to the viewer. Because the graphics are displayed on a fixed screen, the user must focus at that depth to see the graphics sharply. When the virtual object depth and the screen depth are different, the user's oculomotor system sends conflicting signals to the brain about the distance of the object, see Figure 9 on page 22, adopted from [29].

HMDs have the advantage of being better portable and less expensive than projection-based displays. However, HMDs generally have the disadvantage of having smaller spatial resolution than projection-based displays or monitors because they have to be small and lightweight. For ergonomic reasons, the weight and shape of HMDs must be considered because a heavy HMD may cause strain in one's neck muscles from extended use. HMDs may not fit every user, because every person has different head sizes and shapes.

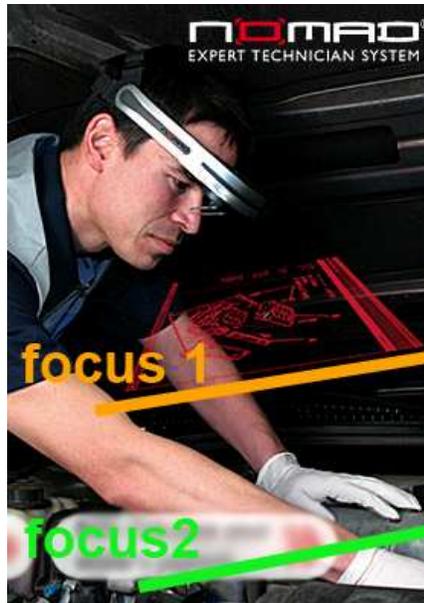


Figure 9: Depth Perception Problems with See-Through HMDs

If the user has to take a closer look on an object in the environment and the HMD hits this object, the HMD itself can also be burdensome and interfere with the user's action. These kinds of problems can hinder the user's experience with the application.

At the moment, no HMD does exist to satisfy industrial requirements, like operational safety, weight, resolution and wearing comfort for up to 8 hours working time.

As a consequence, the user will use this device voluntarily for a few times, but as soon as he knows or thinks he knows the worksteps, he will do the maintenance without the HMD. So the logical consequence is to free the user from this load.

### 3.2.2 Projection Displays

Projection displays are a hybrid between conventional HMDs and surround-screen displays. They project the graphical images into the real environment [30]. Projection displays are ideally suited to collaborative applications in mixed reality because the projection provides correct occlusion cues for both virtual and real objects and because each participant has a correct viewpoint.

Like surround-screen displays, the projection display systems have a number of advantages [31]. Typically, they provide high spatial resolution. In addition, such devices also have a large FOR and FOV. Additionally, real and virtual objects can be mixed in the environment.

One of the biggest disadvantages of such displays is that they are expensive and may require a large amount of physical space to provide a large FOR. As for the laser-based projection, it is not possible to do the projection from the backside. It becomes increasingly difficult for the user not to cast shadows on the display surface by getting closer to the display. But this problem can be solved easily. For instance, multiple projectors can be positioned in the environment redundantly. It is no complex work that the system itself can figure out, if the maintainer is standing between the projector and the object. So the system could project an auxiliary projection next to the actual projection, which indicates the maintainer to step aside. Alternatively to the auxiliary projection, the system could also play a sound if the maintainer occludes the augmentation.

For the maintenance scenario with physical separated what-to-do and where-to-act displays, it is sufficient to display only directional information on the laser-projector display. As the images are not rendered from a tracked user's perspective this display does not cause cue conflicts and lead to cyber sickness. Thus, multiple users can use the projection display at the same time.

### 3.2.3 TabletPC

To create a mobile application, it is essential to work on mobile equipment. That is why a standard desktop PC is beyond question, because one could hardly walk around with this type of device. So, a kind of notebook, UMPC or PDA is suggested. UMPCs and PDAs have the charm that they weight less than notebooks and because of their size, they can be hold by the user easily in one hand. Unfortunately, UMPCs and PDAs have small displays which make it more difficult to create a graphical user interface including images and videos without scrolling the display. Neither UMPCs nor PDAs have the necessary computing power to perform the tracking of the scene and controlling the hybrid display simultaneously at real time. Thus, only a kind of notebook can meet the requirements of mobility and computing power. To increase the level of mobility, a TabletPC was chosen. Figure 10 on page 25 shows the selected TabletPC LifeBook T4220 of Fujitsu Siemens, adopted from [32]. The maintainer can use it as a normal notebook on a table, or in compact form with the display turned around. The maintainer's application is designed for easy accessibility, so most of interaction can be done with the touch screen of the TabletPC.

This TabletPC can be used as a stand-alone AR display type, or as a screen for additional instruction information. When using only the TabletPC the LCD-screen can display the augmentations as well as the instruction information of the current workflow concurrently. But it is also possible, to use the screen of the TabletPC in combination with another AR display type, e.g. the laser projector. So the LCD of the TabletPC acts only as an additional display for the current instruction information, and the augmentations are provided by another display type.

## 3.3 Concluded Setup

Due to the maintenance scenario described in section 1.3 on page 5, and there is no HMD that satisfies industrial requirements at the moment, a HMD is not usable for the kind of maintenance work in focus here. As an alternative to HMD a mobile deployable laser can be used. It can be positioned anywhere in the environment facing the object where the maintenance has to be done. The above mentioned



Figure 10: TabletPC LifeBook T4220

disadvantages of section 3.2.1 on page 20 do not apply to laser-based maintenance.

There is a good reason for using a laser-projector instead of a normal projection display. When operating on non-planar metallic, specular surfaces, the light is not reflected diffusely in all directions, but according to the angle of incidence. So only a small amount of light is reflected to the user. With a laser-projector the light is more intense than the light coming out of a normal projection display. The power of the laser is sufficient to display augmentations under daylight conditions. But nevertheless, long texts cannot be displayed readably.

The laser projection as the only display does not achieve a satisfying result. The projection on a flat surface would be adequate, but this optimistic requirement does not correspond to most environments. Usually a too large projection will be distorted or even divided on multiple surfaces, see Figure 12 on page 27, adopted from [9]. So, the information provided by the laser must be set to a minimum of directional information. As a result, the information has to be split up physically into the where-to-act display which is provided by the laser projection, and the what-to-do display which is provided by an additional display, e.g. the LCD screen of a TabletPC. The where-to-act display indicates the location on the object where the current workstep has to be applied by projecting only a triangle, cross or rectangle

onto the desired location of the object (see Figure 13 on page 27, adopted from [9]), whereas the what-to-do display shows the instructions and additional information about the current workstep. These two single displays can be considered as one hybrid display. Figure 11 on page 26 illustrates the principle of a hybrid display.

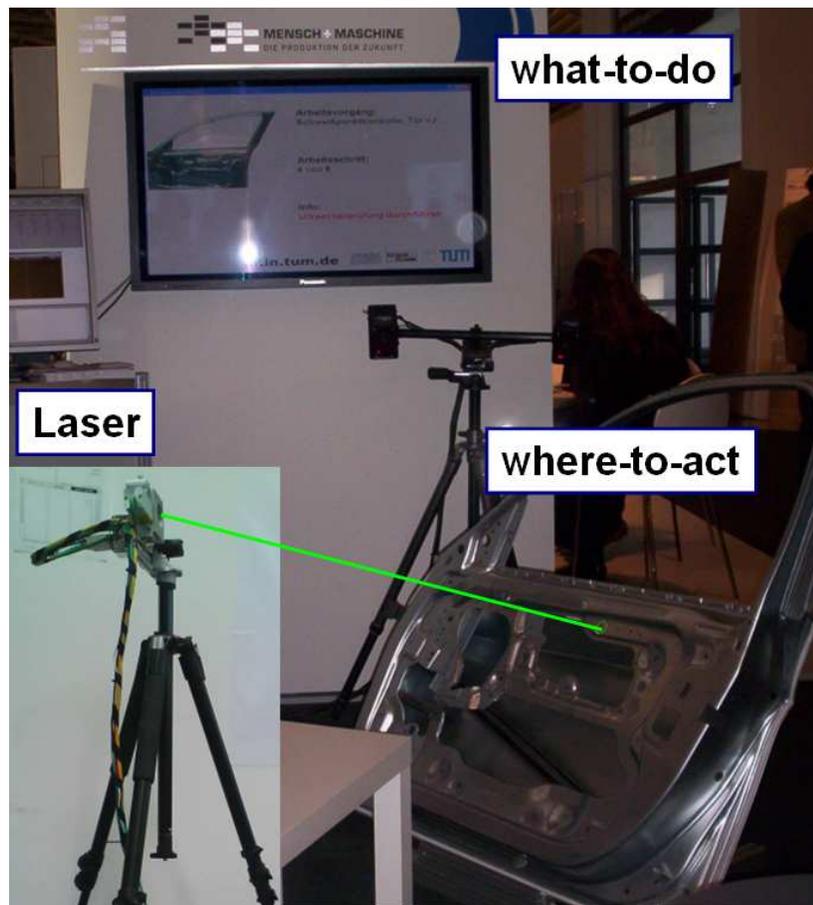


Figure 11: Principle of a Hybrid Display

In contrast to other AR applications, the laser-based approach also minimizes the user's mental transfer from the augmentation to the real world, because the laser projects the information directly onto the desired object in the environment. For instance, this could have been a problem if two screws are very close to each



Figure 12: Laser Projection Divided on Multiple Surfaces due to Inadequate Surface



Figure 13: Different Symbols Projected on a Surface by the Laser

other and the user has to decide which of them to unscrew. With a laser-projection directly on the object those errors like working on the wrong location of the object can be minimized.

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## 4 Resources and Tools

The following section presents the hardware and software tools which were required for the development of the maintenance assistance system. First, the laser-projection unit, including scanner and laser unit are described. Second, the camera used for tracking the environment is described. Third, the software of the UbiTrack Framework will be considered, and finally the Simple Component Framework on which this project is based will be described.

### 4.1 Laser Projection Unit

The laser-projection unit consists of the scanner unit which drives the direction of the laser beam, and the laser itself. The following sections give technical information on both the scanner unit and the laser unit as well as security aspects dealing with the laser.

#### 4.1.1 Scanner

The scanner-unit is a *SCANcube 7* by Scanlab [33]. Figure 14 on page 29 shows the laser projection unit consisting of scanner unit, the laser unit and the tracking camera.

The scanner unit can be accessed with  $\pm 2^{16}$  *bit* less the factor for scale or calibration. This corresponds to the physical resolution of the laser display. The mechanical angle of deflexion amounts  $\pm 11.7$  *degrees*. Thus, the Field of Projection, which is a significant issue of a laser projector, adds up to  $46.8$  *degrees*. The gain error, as well as the zero offset are both  $< 5$  *mrاد*. The non-linearity is below  $3.5$  *mrاد*. These can be compensated by calibration. An example may illustrate the accuracy that is needed for projection displays. To get an accuracy of  $1$  *cm* at a projection distance of  $1$  meter the projection error needs to be  $< 10$  *mrاد* which is about  $0.6$  *degrees*. For a projection distance of  $2$  meters, the projection error needs to be  $< 5$  *mrاد* which is only about  $0.3$  *degrees*. The repeatability of the scanner-unit is  $< 22$   $\mu$ *rad*. The long-term drift over  $8$  hours is  $< 0.3$  *mrاد* plus

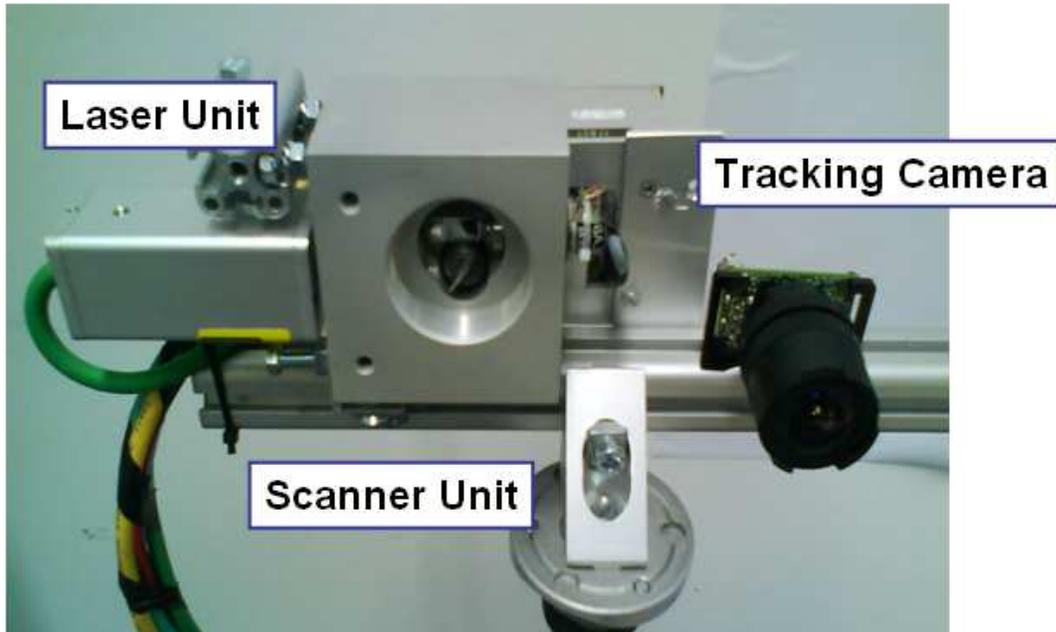


Figure 14: Laser Projection Unit and Tracking Camera

temperature-induced gain and offset drift.

#### 4.1.2 Laser

The laser unit projects with a wave-length of  $532\text{ nm}$ . Thus, the projection is visible as green light. Green light was chosen because the human eye is most sensitive at this wave-length area. So green light seems to be brighter than e.g. red light with the same power. According to the EN 60825-1 norm, this laser-unit fulfils laser class 2. The power of the laser-unit is  $< 1\text{ mW}$ . Its TTL-Modulation is  $99\text{ kHz}$ . This value indicates how fast the laser can be switched on and off.

The laser projection on the object is not concentrated to one small dot, but

because symbols are projected the light is fanned out. So the entire power of the laser is distributed to different locations on the projection display. This issue, and due to the blink reflex of the eye, which signifies the closure of the eye-lid when looking into light, denote this laser-projector as eye-safe.

Table 1 on page 30 gives a short overview of the different laser classes according to the EN 60825-1 norm [34].

Laser Class	Wavelength	max. Power
1	400 – 700nm	$\leq 25 \mu W$
1M	302.5 – 4000nm	$\leq 25 \mu W$
2	400 – 700nm	$\leq 1 mW$
2M	400 – 700nm	$\leq 1 mW$
3R	302.5 – 10600nm	$\leq 5 mW$
3B	302.5 – 10600nm	$\leq 500 mW$
4	302.5 – 10600nm	$> 500 mW$

Table 1: Laser Classes According to EN 60825-1

## 4.2 Camera

The camera used for tracking in this maintenance assistance system is a Point Gray Firefly MV [35]. This colour camera has a IEEE 1394 FireWire interface for connection. It has a  $25 \times 40 mm$  board-level footprint and an external trigger. The sensor is a Micron  $1/3 inch$  global shutter CMOS. The camera can capture images with a resolution of  $640 \times 480$  pixel at a frame rate of 60 *fps*, and a resolution of  $320 \times 240$  pixel at a frame rate of 120 *fps*. The camera supports custom image modes such as pixel binning and region of interest (ROI). Figure 15 on page 31 shows the Point Gray Firefly MV.



Figure 15: Point Gray Firefly MV

Additionally, an objective by Computar is mounted on the camera [36]. It is a special wide-angle lens with a focal length of  $2.6\text{ mm}$ . The maximum aperture ratio of the lens is 1:1.6 and is suited for  $1/2\text{ inch}$  format cameras with a CS-mount. Figure 16 on page 31 shows the used objective by Computar.



Figure 16: Wide-angle Objective by Computar

In the current setup, the camera is used with a reduced frame rate of  $2 - 5\text{ fps}$ . This reduced frame rate makes the tracking more robust and furthermore, the camera is mounted on a tripod and does not need to react quickly on changes about the point of view.

### 4.3 UbiTrack Framework and Markerless Tracking

This section presents the UbiTrack Framework developed by the CAMPAR chair [27]. UbiTrack is a framework which can be used as a middleware between the tracking system and the application. Common AR applications are limited in matters of tracking and sensors. A hybrid tracking approach can extend the range. In this approach, called Ubiquitous Tracking (UbiTrack), data from distributed and diverse heterogeneous tracking sensors is fused automatically and dynamically and then provided to the required application. Every object in the environment has 6 degrees of freedom (DOF). A tracking situation for an object can be described as a Spatial Relationship Graph (SRG). In such a graph, nodes represent the coordinate systems of the objects and edges represent known transformations. See Figure 17 on page 32 for a Spatial Relationship Graph of a tracking situation. UbiTrack intends to solve such tracking and calibration problems for various applications.

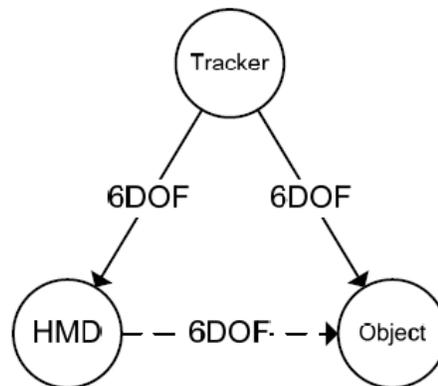


Figure 17: Tracking Situation Described by a Spatial Relationship Graph

The UbiTrack Framework also supports multiple tracking methods. By using the UbiTrack library as a middleware, an application is not fixed on a dedicated tracking method. This is important because the developed maintenance assistance system gets a novel tracking method, which is in the development itself. So, for testing

the maintenance assistance system, the novel tracking method is not mandatory, but another tracking method which is supported by the UbiTrack Framework can be used instead. Switching between different tracking methods is not a complex work, due to using UbiTrack as a middleware. It can simply be changed by loading another dataflow configuration file.

The novel tracking method mentioned above is a markerless tracking method which uses a CAD model of the object that is intended to be tracked. This method is based on the work by Drummond as already presented in section 2 on page 8. The dissertation of Becker which is done in cooperation with EADS deals with the process advancement of this tracking method. This markerless tracking method is also included in the UbiTrack Framework, as so-called blackbox component however. Anyway, this CAD tracking method can be used like any other tracking method of the UbiTrack Framework.

This tracking method claims to deal with a specific object, if there are sufficient edges found and matched with the corresponding CAD model. So, small deviations can be compensated, if there are still enough edges to define this specific object. But light is an issue for this tracking method, as especially round or convex surfaces reflect the light differently every time the incidence of light is different. Unfortunately, this tracking method is not well-suited for the MILAN ADT-ER. The costs for creating an edge-model out of the CAD drawing of the MILAN ADT-ER are too immense.

## **4.4 Simple Component Framework**

The Simple Component Framework is a Java-based component framework that supports basic features to develop distributed applications on base of components easily. The single components communicate via a TCP/IP connection, from and to component ports. Information is sent from an OutPort of the component and to an InPort of another component. These ports can either be buffered or unbuffered, and they support different types of information. The configuration which describes which component is connected to which component is based on the XML file format. The

component manager can run on every system. So this framework provides a basis for a distributed system. More features are not included into the Simple Component Framework, because it should be kept simple, as the name already mentions.

## 5 System Design

This section describes the design of the maintenance assistance system. At the beginning of this section the definition of the WorkFlow and all corresponding elements is explained. Later in this section, the different components used in the UbiDisp Framework are defined. They include Display components, Remote Expert component and the WorkFlow component.

### 5.1 WorkFlow Description

The main aspect for performing the maintenance is the description of the WorkFlow. One WorkFlow describes one maintenance run. The WorkFlow contains all information which is necessary for completing the maintenance. The WorkFlow data is stored in the XML format for easy accessibility and readability. A graphical illustration of the according XSD structure for the maintenance assistance system can be regarded at Figure 18 on page 36. The complete XSD structure of the WorkFlow is listed in Appendix B on page 61.

An additional affirmation that the XML format is well-suited for this WorkFlow is delivered by the Specification S1000D [37] which uses also the XML format for its data modules. The S1000D is applied for creating technical documentation by leading companies of aviation and military industry worldwide.

#### 5.1.1 WorkFlow

A WorkFlow which is defined in the XSD structure file consists of a string *name* and a unique ID with which the WorkFlow can be referred to. This ID which is called *id* is of the integer type. Furthermore, the actual content of the WorkFlow is a number of WorkSteps which are also defined in the structure file. These WorkSteps are of the defined type *workstep*.

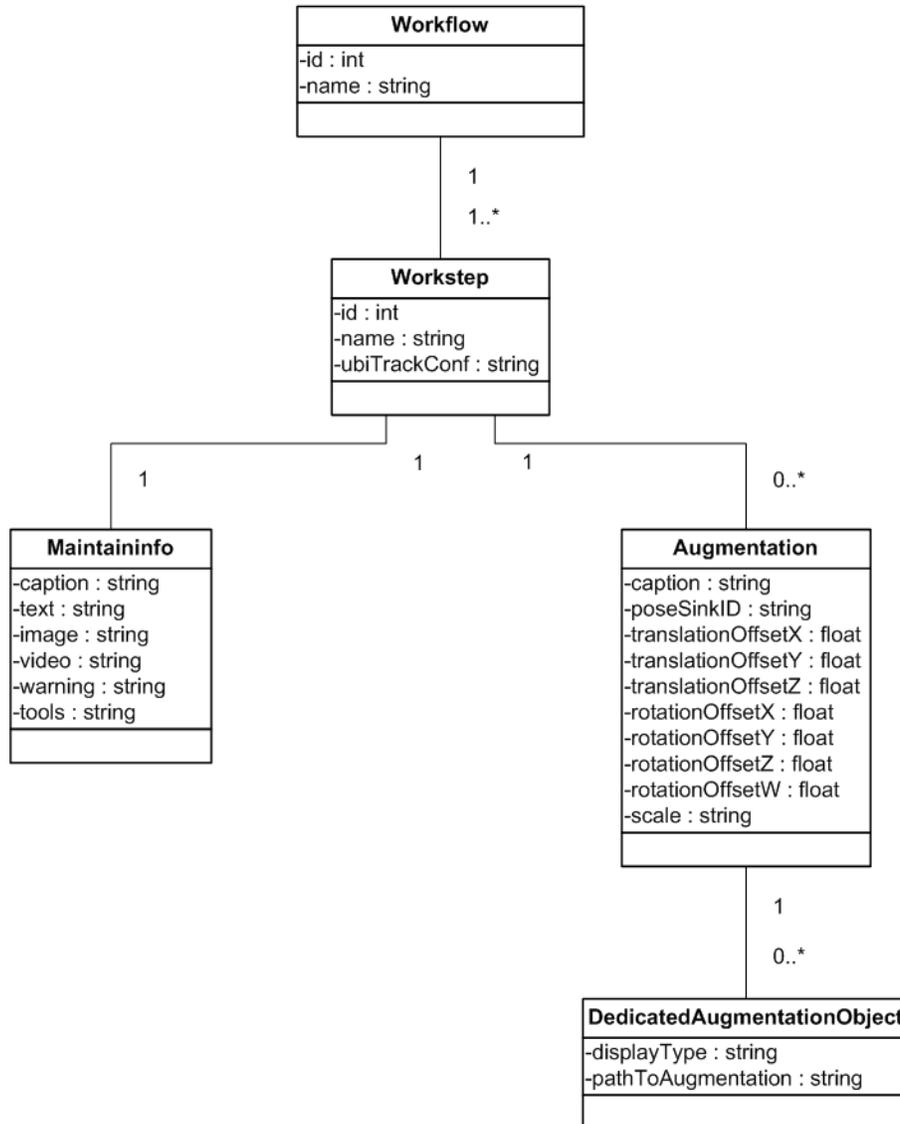


Figure 18: XSD Structure of the Workflow

### 5.1.2 WorkStep

A WorkStep consists of a *name* string and a unique ID of the integer type called *id*. In addition, each WorkStep has its own UbiTrack configuration *ubiTrackConf* whose

type is a string, exactly one instruction set of the defined type *MaintainInfo* about the current WorkStep, the so-called *MaintainInfo*, and a number of information sets for Augmentations. Each of these information sets is named according to the caption of the defined augmentation type. The sequence of WorkSteps is defined by the order in which they are stored in the XML-file. Former considerations included also information sets for Links. So, a reference to the previous and a reference to the next WorkStep was included in every WorkStep. But this feature was abandoned, and the decision was taken, that there is no need in jumping across different WorkSteps, but only a successive completion of the WorkFlow.

### 5.1.3 MaintainInfo

The *MaintainInfo* describes the information which is shown on the what-to-do display. The *MaintainInfo* instruction set has a *caption* string that describes the WorkStep. It also consists of a *text* string which contains a path to a text file in which the instruction of the current WorkStep is stored in plain text. Two analogical strings named *image* and *video* which contain paths to both an image file which illustrates the current WorkStep and a video file that may show the action of the current WorkStep are parts of the *MaintainInfo*, too. Furthermore, a *warning* string which contains a specific warning and a *tool* string which stores a list of tools that are necessary for the current WorkStep can be included. Each of these items is optional, that means there can be an according data set entry containing additional information for the maintainer, but there is no need to be such a data set entry.

### 5.1.4 Augmentation

An *Augmentation* describes the information which is shown on the where-to-act display. In this case, it contains information of the float type about the translation offset named *translationOffsetX*, *translationOffsetY* and *translationOffsetZ*. In addition to that, float type information about rotation is stored in the XSD structure file, named *rotationOffsetX*, *rotationOffsetY*, *rotationOffsetZ* and *rotationOffsetW*. The rotation which is defined with these four float values is stored as quaternion. Furthermore, the string values *scale* which contains the scale of the Augmentation and the *poseSinkID*

are part of the augmentation type. Each Augmentation can have multiple entries for different display types which are called DedicatedAugmentationObjects.

### 5.1.5 DedicatedAugmentationObject

Each DedicatedAugmentationObject consists of a string called *displayType* which contains the type of display which the Augmentation is for, e.g. the Laser, HMD or TabletPC. The type of this DedicatedAugmentationObject which describes the symbol that is shown on the display is a string named *pathToAugmentationObject*.

## 5.2 UbiDisp Framework

This section explicates the different components which are implemented on base of the UbiDisp framework. UbiDisp is a distributed Java-based component framework. It consists of the WorkFlow component, Display component, Remote Expert component and the Tracking component. In this diploma thesis, the WorkFlow component which is the central runtime engine was implemented. Furthermore, one AR-Display was also developed. The choice was made to implement the laser projector. An illustration of the parts that were developed in this thesis are highlighted red on Figure 19 on page 39.

The single components of this framework communicate with each other via a TCP/IP connection. Through this, the system can run distributed on multiple computers. These computers have just to be connected via a network respectively the Internet.

This section begins with the Display components, continues with the Remote Expert component and is finalised with the WorkFlow component. UML diagrams of each component can be seen in Appendix C on page 64.

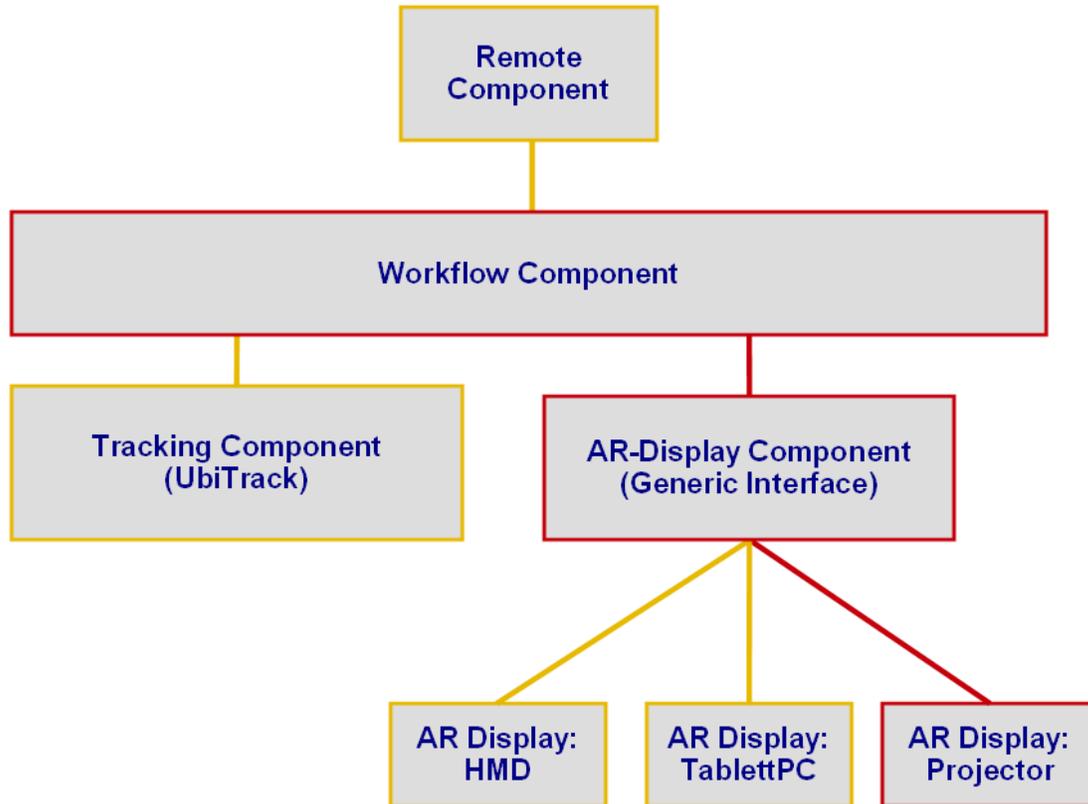


Figure 19: Developed Components in this Thesis

### 5.2.1 AR-Display Component

The Display component of this maintenance assistance system is implemented generically. So, the exchange and connection of multiple different AR-Displays can be done easily. AR-Displays are in this case a laser-projector, an HMD and a TabletPC.

The ARDisplayComponent is the central component for displaying the information. The ARDisplayComponent is implemented as an abstract class which provides only method stubs. It has a buffered InPort *CommandAndMaintainInfoInPort* for

the ARDisplayCommand interface looking for commands, and an unbuffered InPort *AugmentationsInPort* for the ARDisplayMaintainInfo interface which is waiting for maintainInfos. There are also three OutPorts defined in the ARDisplayComponent, the *StatusOutPort*, the *CommandOutPort* and the *WorkstepOutPort*. These OutPorts are implemented in the different DisplayType classes, e.g. the Laser Projector Component. An overview of the ports and interfaces of the ARDisplayComponent can be seen on Figure 20 on page 40.

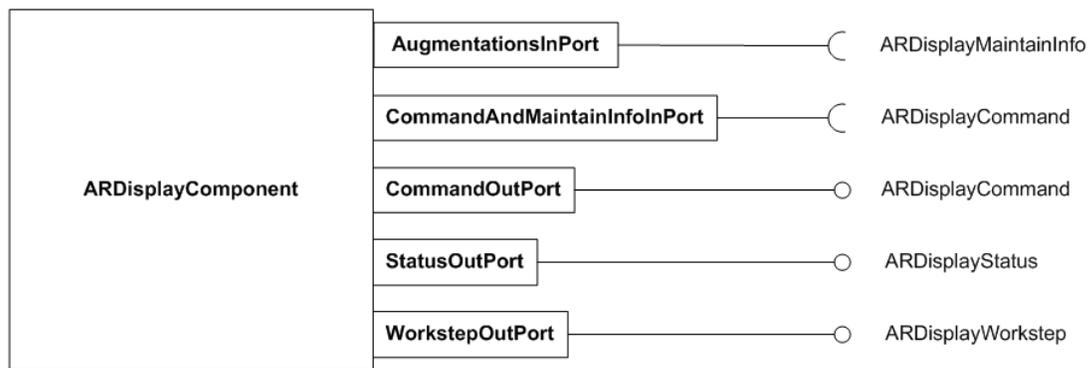


Figure 20: Ports of AR Display Component

Because only a technical demonstrator was created in this thesis, only one DisplayType is implemented. The time and effort of implementing all three DisplayTypes would have gone beyond the scope of this thesis. The decision was to use the laser-projector display. This ScanlabLaserProjectorComponent extends the ARDisplayComponent. The *StatusOutPort* already mentioned above sends messages of the ARDisplayStatus interface, while the *WorkstepOutPort* sends requests of the ARDisplayWorkstep interface type to the WorkFlowComponent. These requests are queries for MaintainInfo and Augmentation information on the next or the previous WorkStep. Figure 21 on page 41 shows the ports and interfaces of the ScanlabLaserProjectorComponent.

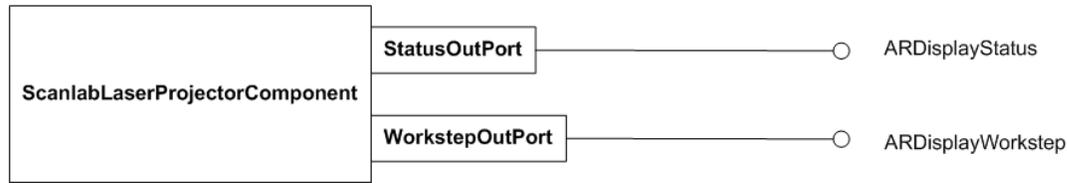


Figure 21: Ports of Laser Projector Component

Up to now there is no code dealing with the implementation of the HMD-Component and the TabletPC-Component. Nevertheless, the method stubs exist in the abstract ARDisplayComponent class. For an implementation of these components the according interpretations of the WorkStep information (MaintainInfo and Augmentation) need to be developed for each of the Display Types.

### 5.2.2 Remote Expert Component

The RemoteExpertComponent provides the possibility of telecommanding the WorkflowComponent. So the only port that is needed in this component is an OutPort. This *MaintainInfoOutPort* supports the ARDisplayCommand interface for sending display commands as well as the ARDisplayMaintainInfo interface which is used for sending MaintainInfo and Augmentation information and the UbitrackCommand interface for sending commands to UbiTrack. Figure 22 on page 42 shows the ports and interfaces of the RemoteExpertComponent.

### 5.2.3 Workflow Component

The WorkflowComponent is the central runtime engine. It reads the necessary information from the Workflow XML-file, and writes back the changes if desired. The WorkflowComponent sends the current WorkStep information to

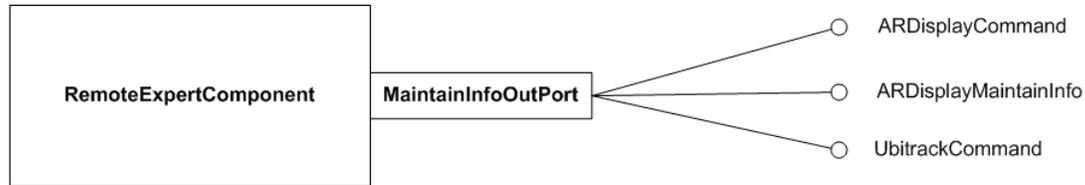


Figure 22: Ports of Remote Expert Component

the ARDisplayComponent. The information can be pushed from interactions with the RunPanel, or be pulled from a request by the DisplayComponent. The WorkflowComponent has three OutPorts. The *MaintainInfoOutPort* sends the MaintainInfo of the current WorkStep according to the ARDisplayMaintainInfo interface. The *AugmentationOutPort* sends the current Augmentations according to the ARDisplayAugmentationInfo interface and the *UbiTrackCommandOutPort* supports sending commands of the UbitrackCommand interface. For looking for WorkStep requests from the ARDisplayComponent a buffered InPort for the ARDisplayWorkstep interface *WorkstepInPort* is required. An illustration of the ports and interfaces of the WorkflowComponent can be regarded on Figure 23 on page 43.

The Graphical User Interface of the WorkflowComponent also offers an Editor for creating new and editing existing workflows. On the left side of the Editor is a tree-view which displays the current Workflow with all present WorkSteps. This tree-view provides an overview of the current Workflow. The tree-view can also be used for navigating in the current Workflow. On the right side there are different forms for editing each part of the Workflow. Because Workflows can become extremely complex, a listing of all possible forms would become unclear and confusing. So, only these forms are visible on the right side, which belong to the selected Workflow part of the tree-view. This keeps the Editor frame relatively small. Thus, scrolling of the screen can be avoided. Small icons in the tree-view

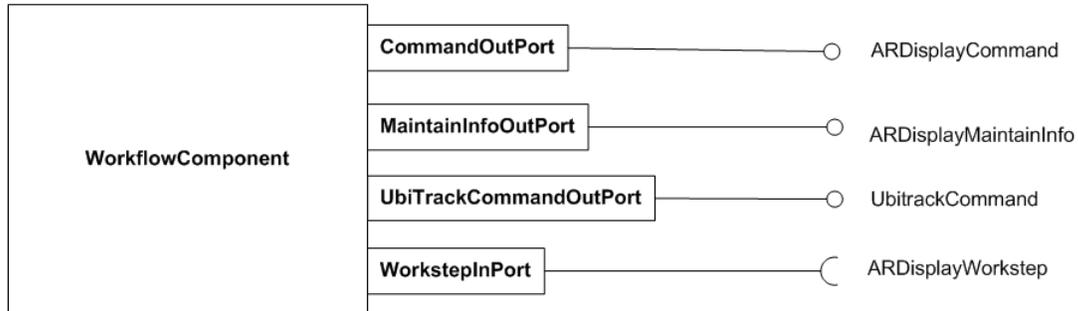


Figure 23: Ports of Workflow Component

create also an intuitive impression of the WorkFlow tree-view. Figure 24 shows the Editor of the WorkFlowComponent.

#### 5.2.4 Installation of UbiDisp

To make the UbiDisp project run in the Eclipse IDE [38] for further development, some settings and preparations are required. Therefore, environment variables of the computer have to be adapted, and configuration properties in the Eclipse development environment have to be changed.

##### 5.2.4.1 Environment Variables

Some environment variables of the computer have to be adapted, to make the UbiDisp project run. This section will not provide information on how to change environment variables in general. But lots of HowTos about changing environment variables of a windows computer can be found on the Internet.

The *PATH* variable needs to be extended, or if it does not yet exist it has to be created. The path where the laser-projector project has been checked out has to be included to the *PATH* variable, e.g. `C:\SVN\laserprojector`.

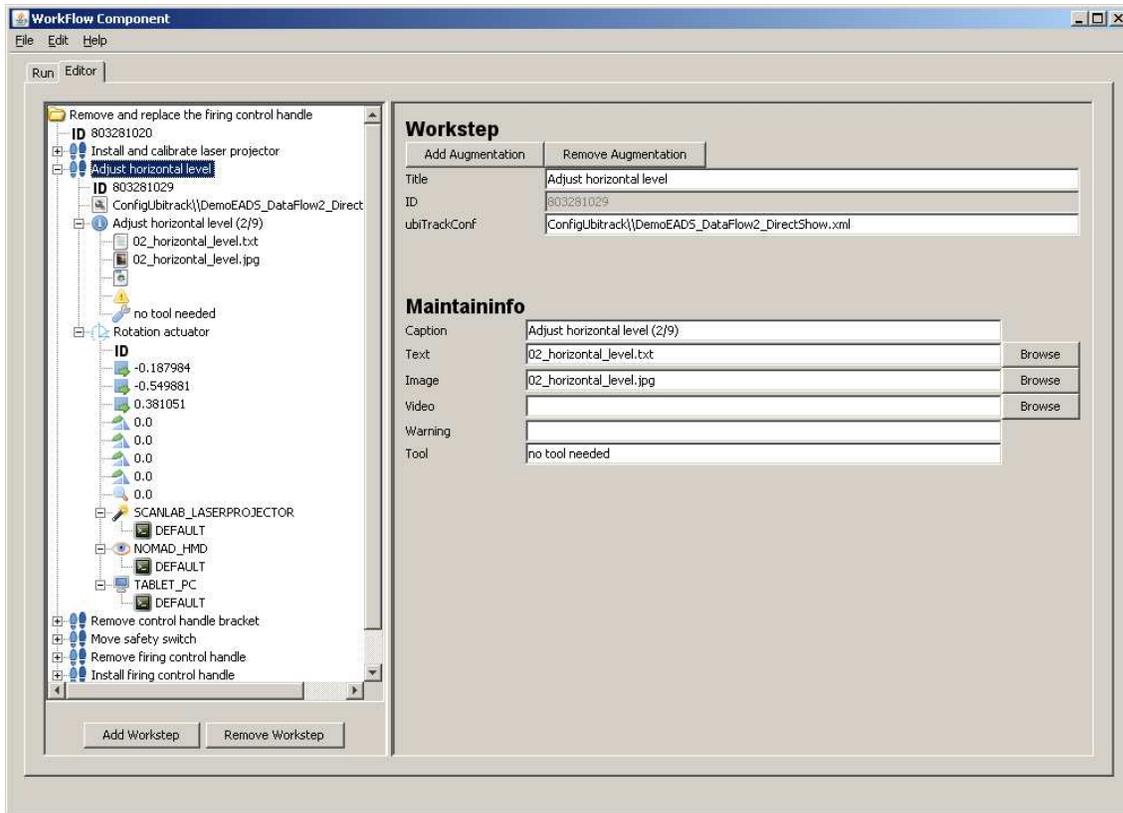


Figure 24: Editor of Workflow Component

Lets call it <LaserDir> for illustration. Furthermore, the complete path to the <LaserDir>\UbitrackLIB directory, which is a subdirectory of the project directory, needs to be included, as well as all three <LaserDir>\UbitrackLIB\dependenBINS\DSVideoLib directory, <LaserDir>\UbitrackLIB\dependenBINS\freeGlut directory and <LaserDir>\UbitrackLIB\dependenBINS\OpenCV directory. Figure 25 on page 45 shows the adapted environment variables.

#### 5.2.4.2 Run Dialog

The Run Configuration in Eclipse of the laser-projector project needs to be changed, too. The Run Configuration can be accessed by Menu → Run → Open Run

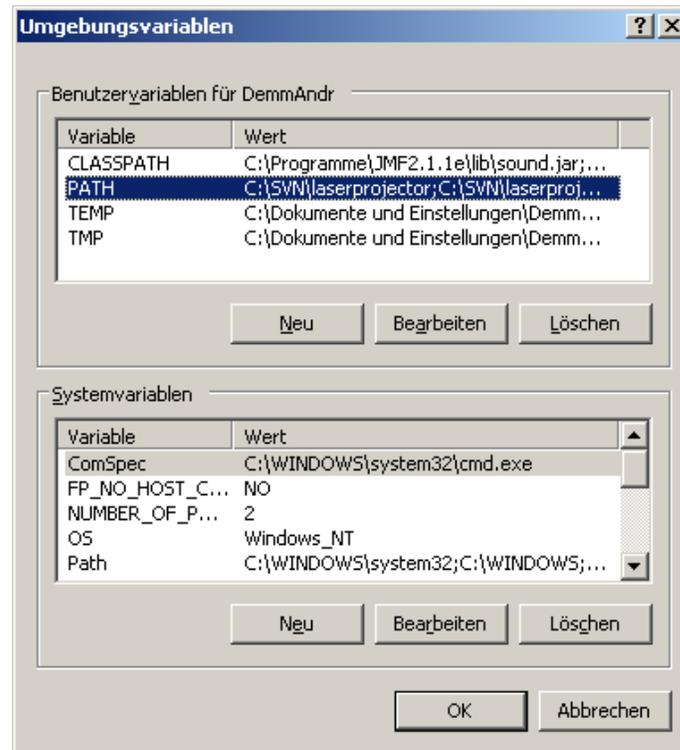


Figure 25: Environment Variables

Dialog. First, on the left side the Java Application according to the laser-projector project has to be selected. Second, clicking the *Arguments* tab has to be clicked. Figure 26 on page 46 shows the Run Dialog with selected Arguments tab. The expression `XML=ConfigUbiDisp\UbiDispDeployment.xml` needs to be included to the Program arguments, and `-Djava.library.path=<LaserDir>;<LaserDir>\UbitrackLIB` needs to be included to the VM arguments.

### 5.2.4.3 Java Build Path

The Java Build Path of the project has to be adapted, too. The Java Build Path can be accessed in Eclipse in the project properties. The Simple Component Framework has to be added in the Projects tab. The more complex part is

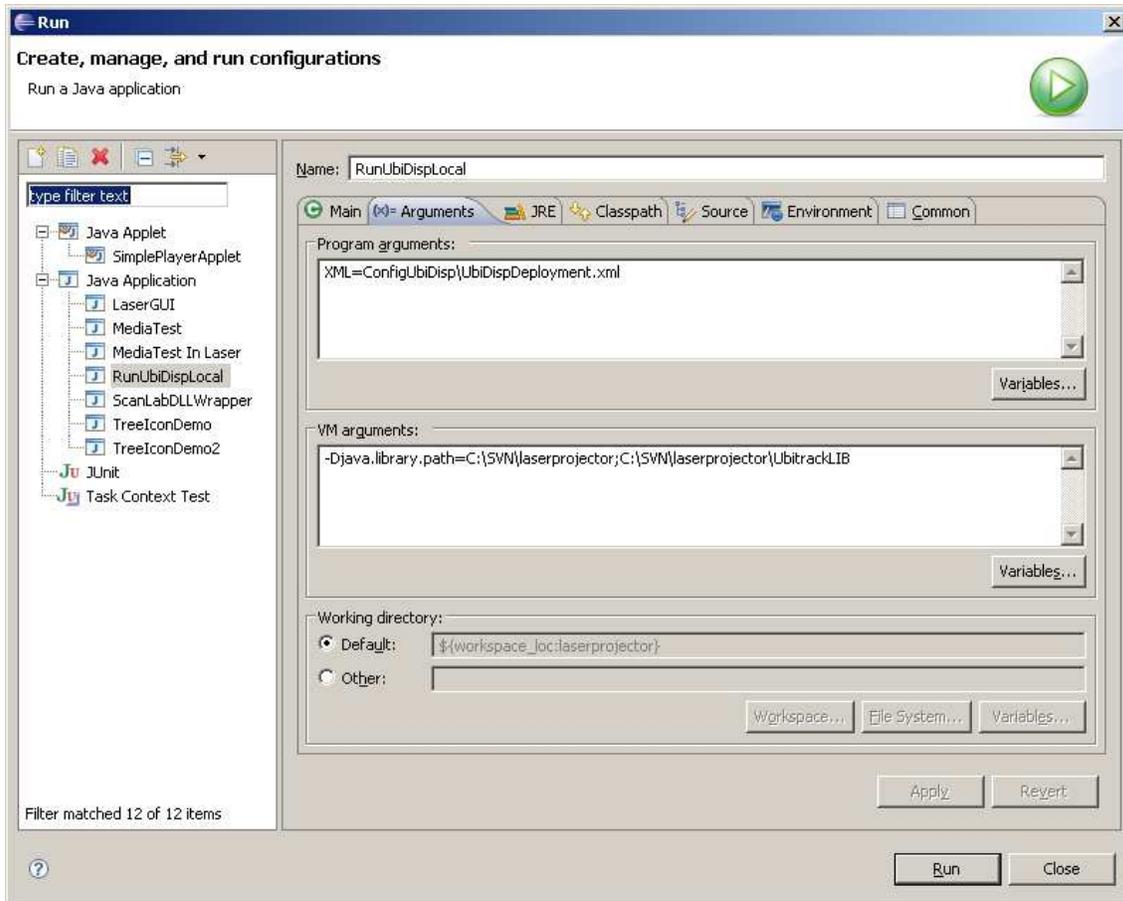


Figure 26: Run Dialog

to add external JARs to the Libraries tab. The required JARs are located in the `<LaserDir>\JarExt` directory and its subdirectories. One additional JAR is required, too. The `ubitrack.jar` file is located in the `<LaserDir>\UbitrackLIB` directory. A complete list of all required external JARs and their locations can be regarded on Figure 27 on page 47.

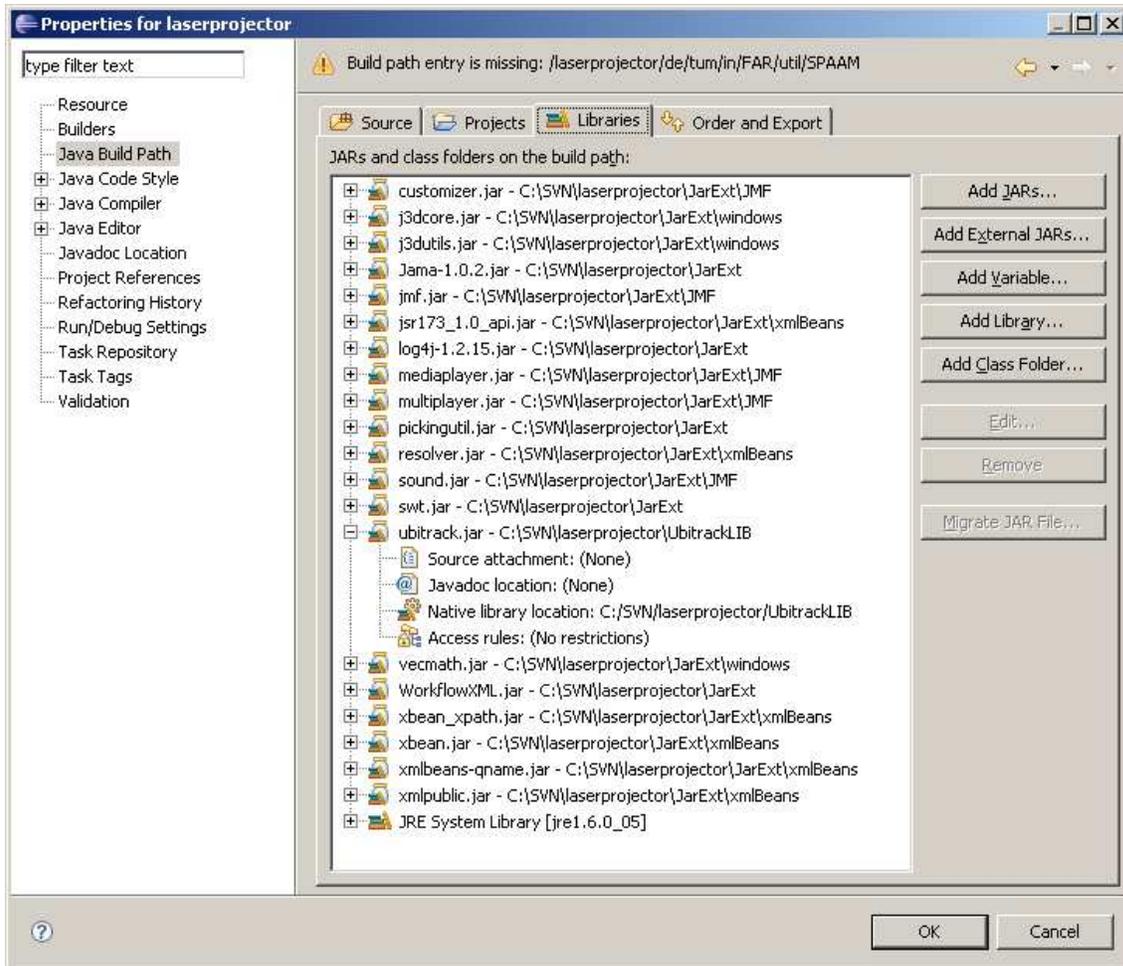


Figure 27: Java Build Path

## 6 Use Case

This section describes the Use Case that was examined at the end of this thesis. The task was to make the developed components run altogether, and to provide a proper WorkFlow. At the beginning of this section the setup of the Use Case is illustrated. Later, the action of the Use Case itself is explained and finally, the results that arose from the Use Case are shown.

### 6.1 Setup

The maintenance object where the Use Case was performed on is a mockup of the MILAN ADT-ER. As the tracking of the object is a basic issue, some decisions were made which tracking method to use. Unfortunately, for this Use Case the markerless tracking method has not yet been adapted, which is not part of this thesis. So, it was decided to use optical marker tracking. It is important to have the markers always at the same position of the MILAN, that there is no need to calibrate the points that have to be shown every time. The markers are not attached on the MILAN itself, but on a fix holding for quick mounting and unmounting the markers. Figure 28 on page 49 shows the MILAN with attached markers. One marker is attached on every side of the fix holding, in order to have one marker visible for the camera no matter how the MILAN is rotated.

After the markers are attached on the MILAN, the points where the augmentations are ought to be, can be calibrated. This can be done with the help of a special point calibration tool. The tip of this tool needs to be put onto the according points of the MILAN. The point calibration tool can be regarded on figure 29 on page 50.

The resulting points where the augmentations are ought to be, need finally to be integrated into a maintenance WorkFlow with the help of the editor of the WorkFlow Component.



Figure 28: MILAN mockup with Attached Marker

## 6.2 Experiment

The action of the Use Case is constructed in the following way: The Use Case consists of 9 WorkSteps that instruct the user to disassemble the firing handle of the MILAN, check a cable connection, and reassemble the firing handle again.

The first WorkStep is to set up the laser and camera unit. After this WorkStep the camera is positioned about 2 meters away from the MILAN and the attached marker of the MILAN is tracked by the software. An affirmation of tracking the

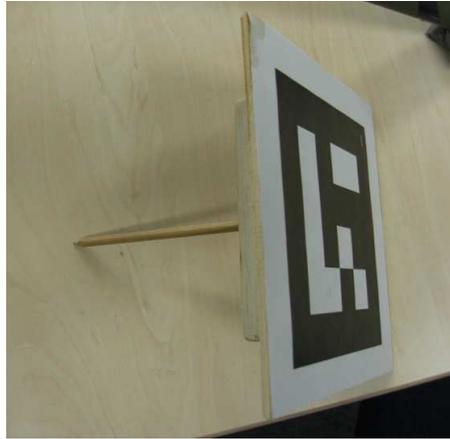


Figure 29: Point Calibration Tool

marker is shown by displaying an augmentation, which consists of a cross surrounded by a circle, at the center of the marker. All augmentations in this Use Case are of the same type. However, it is possible to project different symbols, but it is not part of this experiment to find out what augmentation is the most suitable for a specific position. Thus, only one clearly noticeable type of augmentation is used in this experiment. Figure 30 on page 51 illustrates the first WorkStep. On the left side, the what-to-do display can be seen. The right side shows the where-to-act display.

The second WorkStep consists of rotating the MILAN if required, in order to get access to the horizontal level controller, and rotate this controller counter-clockwise so that the launcher plate of the MILAN is not horizontal anymore, but fully risen. An augmentation is shown on the horizontal level controller to lead the way for the user. To complete this WorkStep the MILAN needs to be rotated again, get access to the firing handle. Figure 31 on page 52 illustrates the second WorkStep.

WorkStep 3 contains the disassembly of the firing handle bracket by unscrewing 3 screws. One augmentation is shown on each screw position. The augmentations are displayed simultaneously and not one after another, because the sequence of

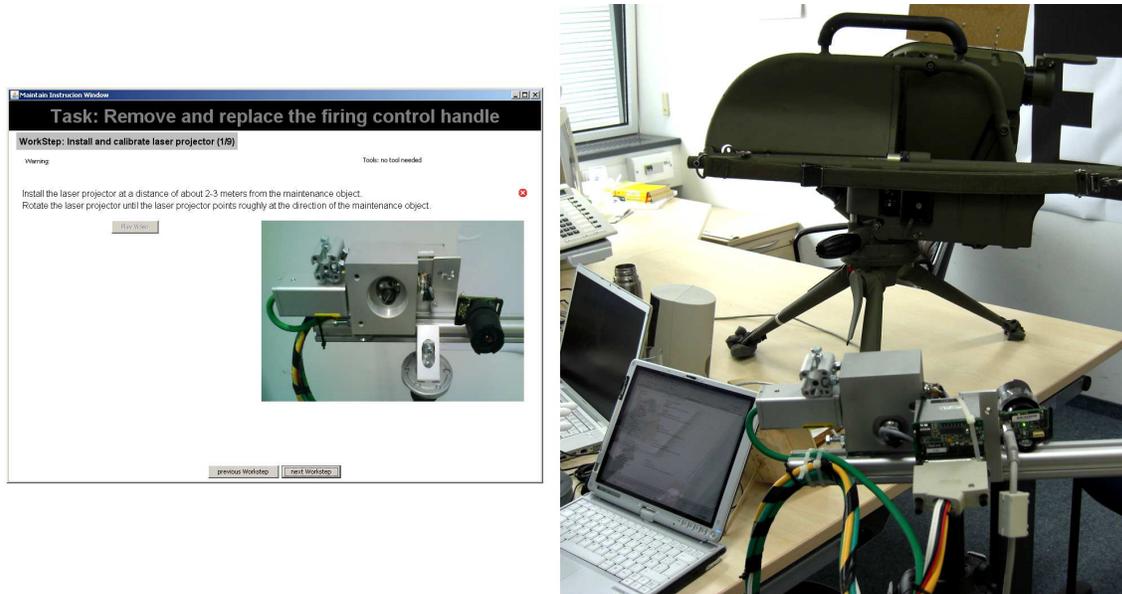


Figure 30: WorkStep 1 of the Use Case

unscrewing does not matter. Figure 32 on page 53 shows the augmentations and instructions during this WorkStep. These augmentations are a little inaccurate due to improvisational tracking.

The fourth WorkStep is moving the safety switch of the firing handle to the left, in order to get better access to the screws behind, needed in the following WorkStep. One augmentation is projected onto the safety switch. Figure 33 on page 54 illustrates the fourth WorkStep.

WorkStep 5 is removing the firing handle from the MILAN, after unscrewing the 4 screws that fix the firing handle on the MILAN. One augmentation is projected to each of the 4 positions of the screws simultaneously. In Addition to the text of the MaintainInfo, a warning is shown on the what-to-do display, too. This warning advises the user not to damage the cable between firing handle and MILAN during disassembly of the firing handle. Figure 34 on page 54 illustrates the fifth WorkStep.

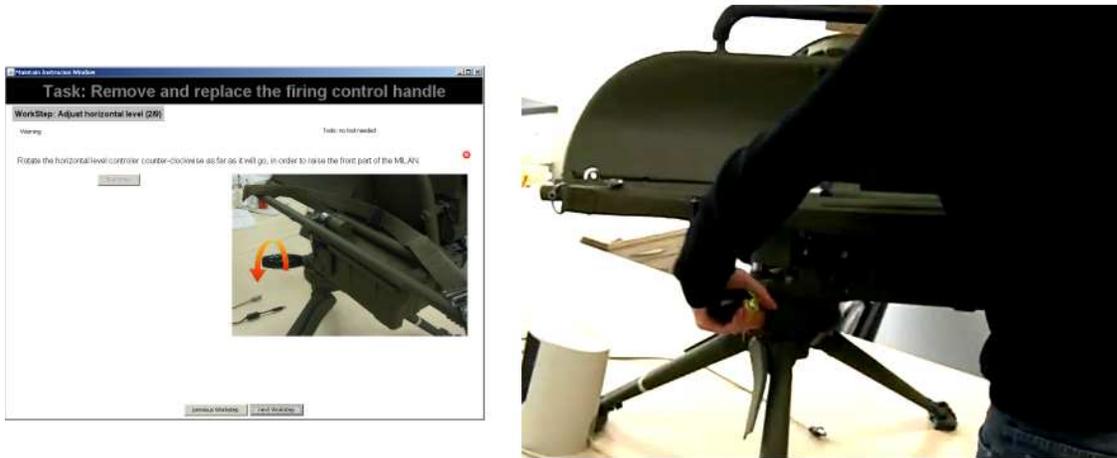


Figure 31: WorkStep 2 of the Use Case

After checking this cable, the WorkSteps 6 to 9 guide the user during assembly of the firing handle to the MILAN. These WorkSteps are quite the same as WorkStep 2 to 5, but reversed analogously.

### 6.3 Results

Performing this Use Case led to some results. Some of the augmentations that were projected onto the object were occluded by the object itself. This may happen when projecting to hardly accessible regions of the object. A tracking method that is based on the CAD model of the object may detect such an occlusion, however. Some surfaces seemed to be inadequate for projection. The augmentation on the horizontal level controller for instance was hardly noticeable, because it is painted in black colour.

Despite of these issues, the hybrid display could fulfil its task to guide a user

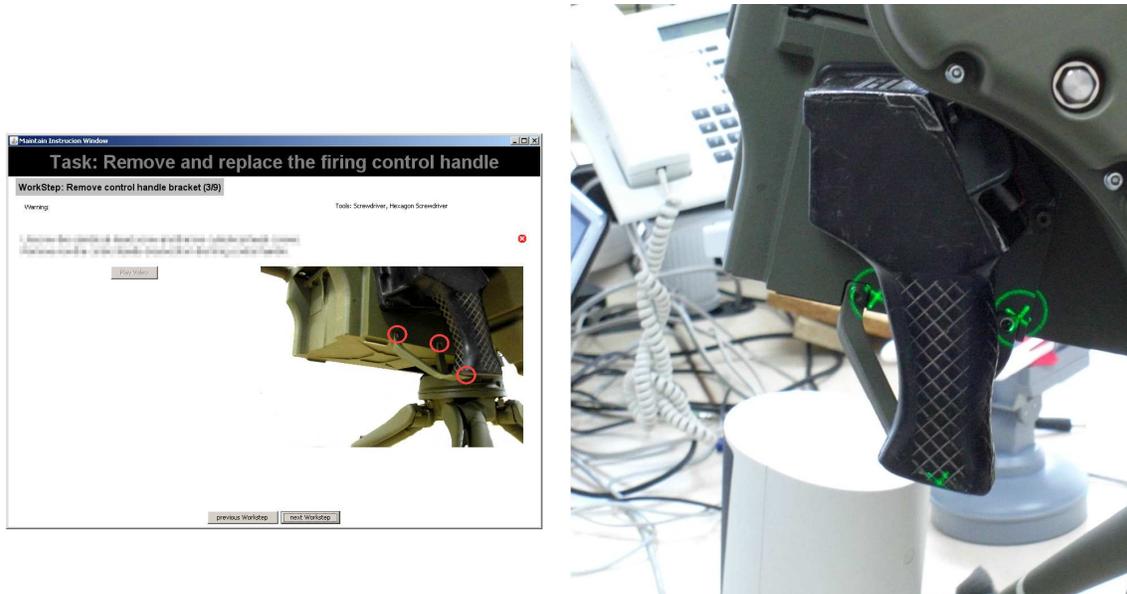


Figure 32: WorkStep 3 of the Use Case

through a defined WorkFlow. The instructions on the what-to-do display could be applied to the positions on the objects shown by the augmentations on the where-to-act display.

This quite difficult Use Case was chosen to identify the present weak points of the system. Hardly accessible regions of the object may be augmented with a combination of special metaphors on the what-to-do and where-to-act display. A rotary arm on the tripod on which the laser-projector is mounted may also improve the support of the maintenance assistance system.

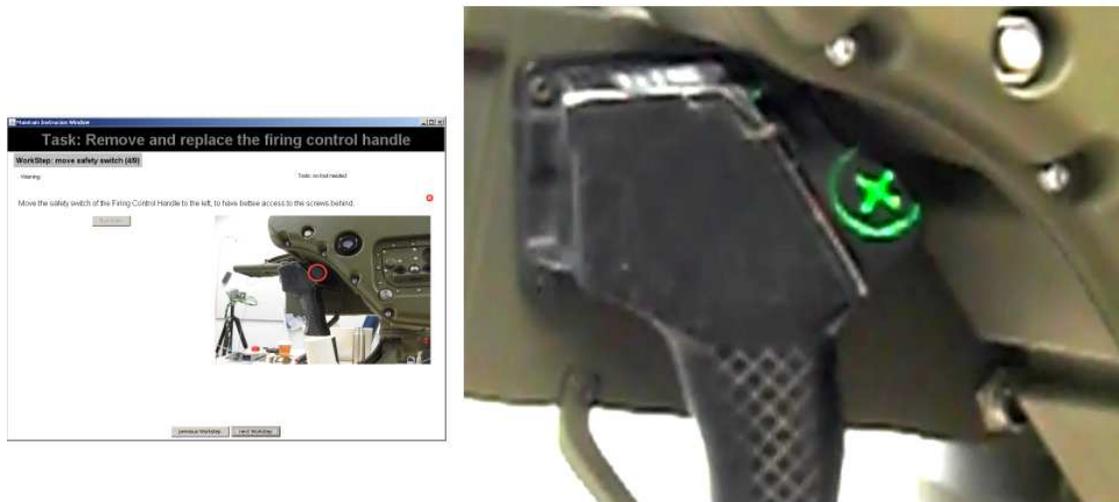


Figure 33: WorkStep 4 of the Use Case



Figure 34: WorkStep 5 of the Use Case

## 7 Summary

This last section gives a summary of the diploma thesis. Continuitive work that may be done in the future to enhance the maintenance assistance system is shown here. Finally, the conclusion of the development of the maintenance assistance system is presented.

### 7.1 Future Work

This maintenance assistance system was developed within the scope of a diploma thesis. The main focus here was to create a technical demonstrator to show the capability of maintenance assistance with the help of Augmented Reality. So, several "nice-to-have"s were left out for temporal reasons.

Additional AR-Display types besides the AR-Laser projector can be included to the system. Interfaces that support the integration of an HMD or a TabletPC are already available. The Display Component was developed generically, so the integration of these other displays is no complex work.

The MaintainInfo information set for the Use Case used in this thesis was created manually. To enhance the flexibility of the system, it is possible to create a new Database Component that delivers the information needed by the maintenance assistance system from some kind of data modules which are stored in an extensive database.

A tracking method which is based on the CAD model of the object may detect a tracking situation where the position of the augmentation is occluded by the object itself in hardly accessible regions or by the user. To avoid such an occlusion, the tracking system may advise the user to rotate the object or to step aside. Using other metaphors like "look around this corner" may improve the support, too.

Another method to avoid occlusion is setting up small mirrors in the environment. These markers are tracked by the system either with a marker or with a model based tracking method. The laser projector can use the mirrors to project onto parts

of the object where deflection is required to reach this region of the object. This principle is similar to using the bank of a billiard table. This method can also be used to avoid multiple laser projectors in the environment.

With the help of this maintenance assistance system, the training level of the maintainers can be decreased. This can cause different levels of knowledge on a specific object, however. As a solution, the maintenance assistance system may provide different level of instruction, according to the knowledge level of each maintainer.

As an upgrade for repair, this system may provide a search along a fault tree. The maintainer gives input about the system and the occurred error, and the system suggests a procedure to isolate and solve the problem according to the probability of failure of different mounting parts. If the error was not removed within the first act, the system suggests the part with the next highest probability of failure, until the error was found.

## 7.2 Conclusion

The development of the concept for the AR-based maintenance assistance system from section 3.1 on page 14 leads to some results.

Some of the augmentations that are projected onto the object were occluded by the object itself. This may happen when projecting to concave regions of the object. A tracking method that is based on the CAD model of the object may detect such an occlusion and react on it, however.

Some surfaces seem to be inadequate for projection. This may be because the surface is painted in black colour or it is specular. To increase the detection of augmentations, using high-power lasers or flashing augmentations are needed in such cases. Nevertheless, nearly all augmentations are easily noticeable on the object.

Despite of these issues, maintenance assistance system which is based on the hybrid display can fulfil its task to guide a user through a defined Workflow. The

instructions on the what-to-do display can be applied by the user to the positions on the objects shown by the augmentations on the where-to-act display.

This thesis has shown that splitting up the maintenance assistance information is advantageous. Of course, there is room for a lot of improvements, but the creation of a technical demonstrator was successful.



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## A Glossary

<b>AR</b>	<i>see Augmented Reality</i>
<b>Augmented Reality</b>	Augmented Reality is a newly emerging technology by which a user's view of the real world is augmented with additional information from a computer model. See section 1.1 on page 2 for more detailed information.
<b>CAD</b>	<i>see Computer Aided Design</i>
<b>Computer Aided Design</b>	CAD is the use of computer technology to aid in the design of a product [39].
<b>Degree of Freedom</b>	The unique situation of an object in the environment can be defined by six degrees of freedom. Three of them are coordinate values, and the other three are rotation angles.
<b>DOF</b>	<i>see Degree of Freedom</i>
<b>Extensible Markup Language</b>	XML is a general-purpose specification for creating custom markup languages. It allows the users to define their own elements, thus it is applicable to share structured data.
<b>Field of Regard</b>	The Field of Regard refers to the amount of the physical space surrounding the user in which visual images are displayed. For example, if the user stands in a cylindrical display, the display would have a 360-degree FOR [40].
<b>Field of View</b>	The Field of View refers to the maximum number of degrees of visual angle that can be seen instantaneously on a display. For example, with a large, flat projection screen, the horizontal FOV might be about 80 or 120 degrees [40].
<b>FOR</b>	<i>see Field of Regard</i>
<b>FOV</b>	<i>see Field of View</i>
<b>Head Mounted Display</b>	A HMD is a visual display device attached on the user's head. The main goal of an HMD is to place images directly in front of the user's eyes [41].

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<b>Head Mounted Laser Projector</b>	The Portable or Head Mounted Laser Projector is the prototype of a user centered 3D instruction placement system for industrial applications [42].
<b>HMD</b>	see <i>Head Mounted Display</i>
<b>HMLP</b>	see <i>Head-Mounted Laser Projector</i>
<b>ID</b>	Identity, Identifier
<b>MILAN</b>	French: <i>Missile d'Infanterie léger antichar</i> . The MILAN is a portable and vehicle-mountable anti-tank guided missile for the light infantry. The enhanced version MILAN ADT-ER consists of the launcher system MILAN ADT (advanced technology) and the guided missile MILAN ER (extended response) with a range up to 3000 meters.
<b>PDA</b>	see <i>Personal Digital Assistant</i>
<b>Personal Digital Assistant</b>	A PDA is small handheld computer commonly used as an organizer.
<b>TCP/IP</b>	see <i>Transmission Control Protocol/Internet Protocol</i>
<b>Transmission Control Protocol / Internet Protocol</b>	TCP/IP is the standard protocol for a reliable transport of data over networks.
<b>Ultra Mobile PC</b>	An UMPC is a small form of a TabletPC. They have a touch sensitive screen with a screen size of about 7 inch.
<b>UMPC</b>	see <i>Ultra Mobile PC</i>
<b>XML Schema Definition</b>	XML Schema Definition is a way to define the structure of XML files and are in themselves also defined as XML files.
<b>XSD</b>	see <i>XML Schema Definition</i>
<b>XML</b>	see <i>Extensible Markup Language</i>

---

## B XML Schema Definition of the Workflow

```
<?xml version="1.0" encoding="UTF-8"?>
<schema
xmlns="http://www.w3.org/2001/XMLSchema"
targetNamespace="http://ar.in.tum.de/Ubidisp"
xmlns:ubid="http://ar.in.tum.de/Ubidisp">

<element name="workflow">
  <complexType>
    <sequence>
      <element name="id" type="integer" />
      <element name="name" type="string" minOccurs="0" />
      <element ref="ubid:workstep" maxOccurs="unbounded" />
    </sequence>
  </complexType>
</element>

<element name="workstep">
  <complexType>
    <sequence>
      <element name="id" type="integer" />
      <element name="name" type="string" minOccurs="0" />
      <element name="ubiTrackConf" type="string" />
      <element ref="ubid:maintaininfo" />
      <element ref="ubid:augmentation" minOccurs="0" maxOccurs="unbounded" />
    </sequence>
  </complexType>
</element>

<element name="maintaininfo">
```

```
<complexType>
  <sequence>
    <element name="caption" type="string" minOccurs="0" />
    <element name="text" type="string" minOccurs="0" />
    <element name="image" type="string" minOccurs="0" />
    <element name="video" type="string" minOccurs="0" />
    <element name="warning" type="string" minOccurs="0" />
    <element name="tools" type="string" minOccurs="0" />
  </sequence>
</complexType>
</element>

<element name="DedicatedAugmentationObject">
  <complexType>
    <sequence>
      <element name="displayType" type="string" />
      <element name="pathToAugmentationObject" type="string" />
    </sequence>
  </complexType>
</element>

<element name="augmentation">
  <complexType>
    <sequence>
      <element name="caption" type="string" minOccurs="0" />
      <element name="poseSinkID" type="string" />
      <element name="translationOffsetX" type="float" />
      <element name="translationOffsetY" type="float" />
      <element name="translationOffsetZ" type="float" />
      <element name="rotationOffsetX" type="float" />
      <element name="rotationOffsetY" type="float" />
      <element name="rotationOffsetZ" type="float" />
      <element name="rotationOffsetW" type="float" />
    </sequence>
  </complexType>
</element>
```

```
<element name="scale" type="string" />
  <element ref="ubid:DedicatedAugmentationObject" minOccurs="0"
    maxOccurs="unbounded" />
</sequence>
</complexType>
</element>
</schema>
```

## C UML Diagrams

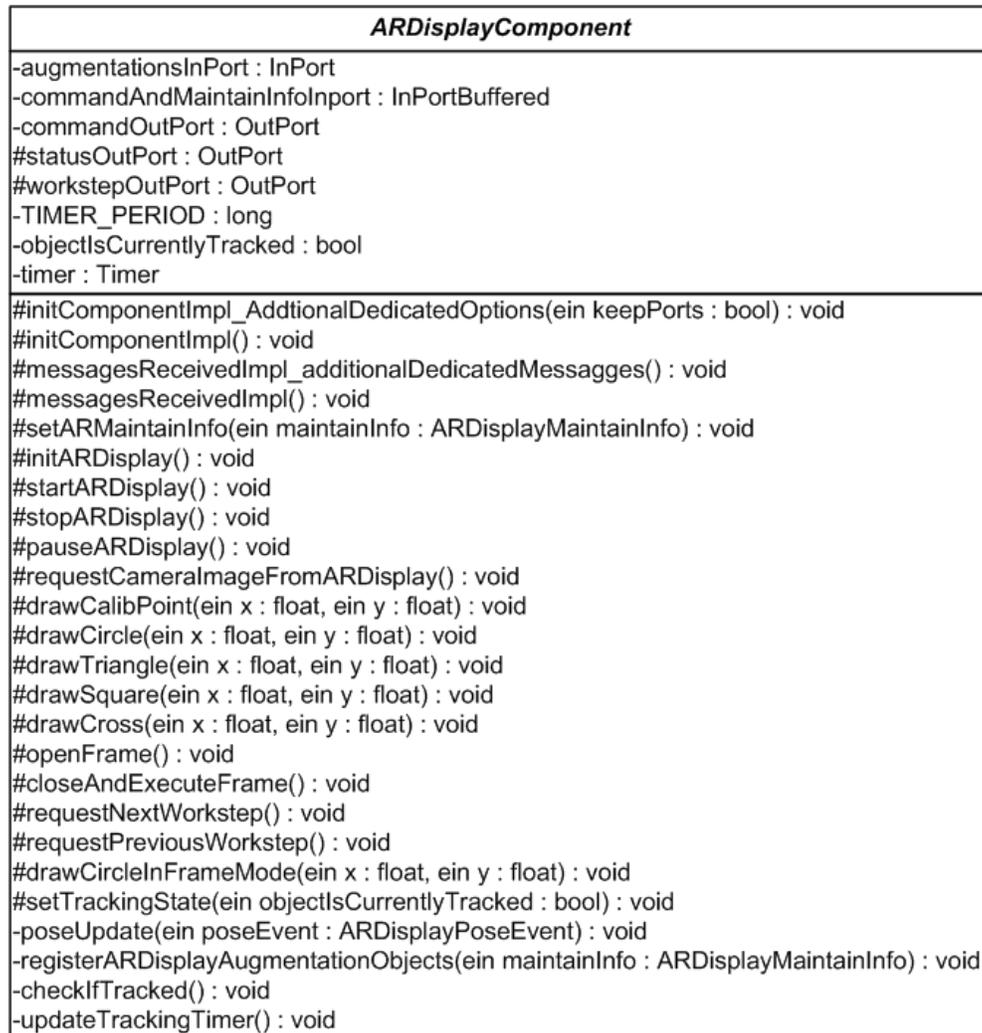


Figure 35: UML Diagram of AR Display Component

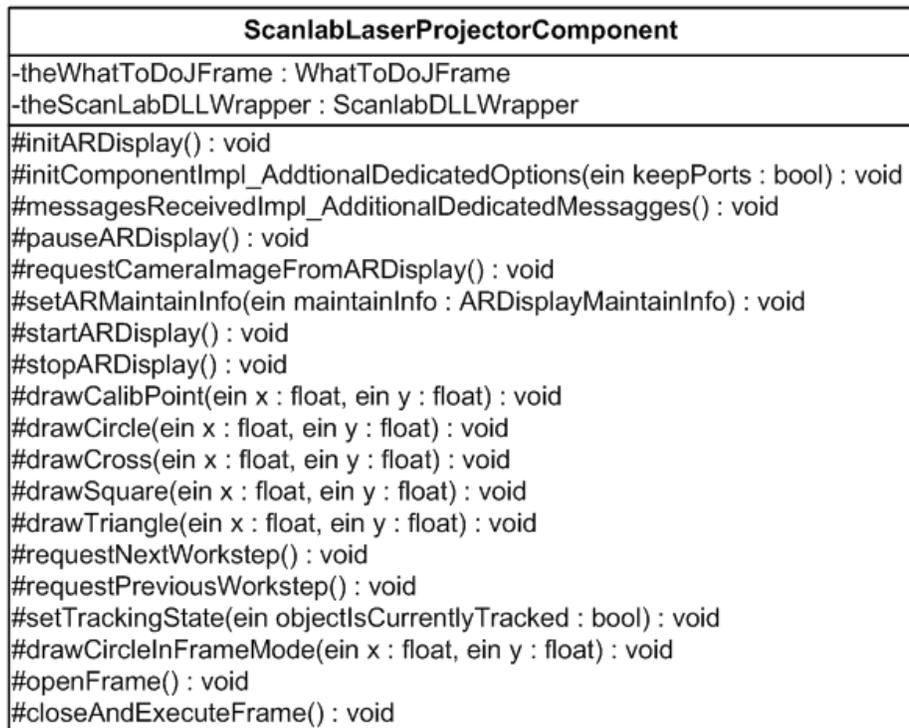


Figure 36: UML Diagram of Laser Projector Component

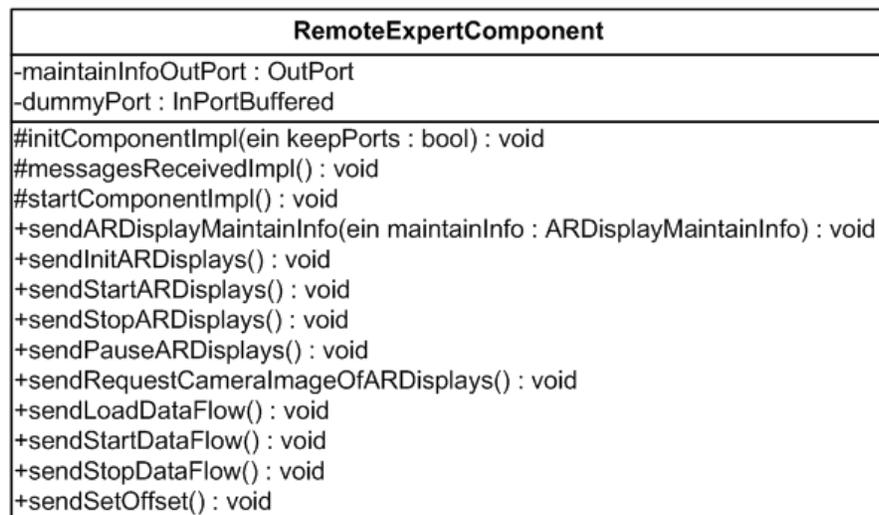


Figure 37: UML Diagram of Remote Expert Component

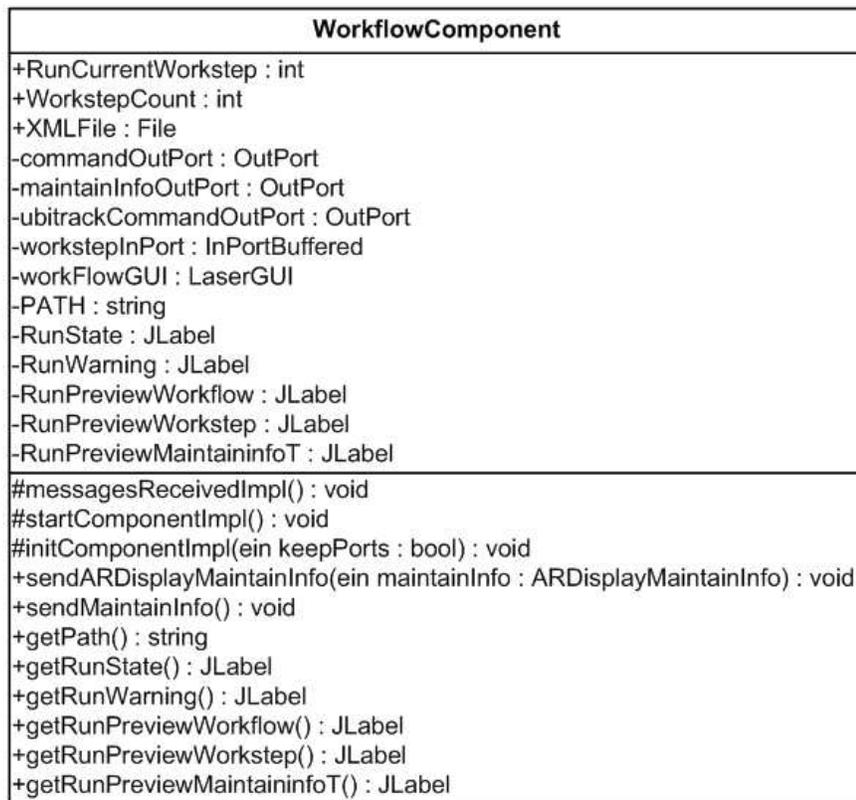


Figure 38: UML Diagram of Workflow Component

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