Deliverable 4.5

Concept of Digitally Augmenting Human Work

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Authors (all contributors to the Deliverable)

Organization	Name	Chapters
ViF	Michael Schmeja	1,2,6
ViF	Michael Spitzer	4,5
ViF	Manfred Rosenberger	3

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Publishable Executive Summary

Virtual Vehicle Research GmbH is developing a holistic concept for digitally augmenting human work taking advantage of e.g. Augmented or Mixed Reality technologies and will then implement this concept within industrial demonstrators.

Seamless interaction across different IT-tools provides product information without media breaks. Subsequently, context-relevant information will be displayed in the field of view of the worker enabling smooth operation and avoiding cognitive overload.

Better access to information and analytics allows cutting production times while increasing product quality and reducing waste due to better-informed decisions.

The provision of additional e.g. step-by-step guidance will further decrease the probability of errors in the assembly process especially in a single-lot production environment.

The resulting concept of digitally augmenting human work was successfully developed within two industrial use cases.

As a next step this concept will be implemented and evaluated within an industrial demonstrator and will be then documented in Deliverable 4.6.

Key Words

Augmented Reality, Technology Enhanced Learning, On-the-job Training, Special Machine Engineering, Smart Manufacturing, Robot Teach-in

Contents

List of Figures

1 Introduction

1.1 Overall Goal of the ECSEL Project iDev40

The main objective of the iDev40 project is to achieve a disruptive or "breakthrough change" step toward speedup in time to market by digitalizing the European industry, closely interlinking development processes, logistics and manufacturing. Ultimately, the project aims at suitable digital technology advancements to strengthen the electronic components and systems industry in Europe. It addresses various industrial domains with one and the same approach of digitalization towards competitive and innovative solutions.

The new concept of introducing seamlessly integrated development together with automation and network solutions as well as enhancing the transparency of data, its consistence, flexibility and overall efficiency will lead to a significant speedup in the time to market (T2M) race.

iDev40's unique approach addresses:

- AI learning, Data Life Cycle Management and IP Protection,
- Embedding Digital Development in Digital Production (the digital twin),
- Closing the Knowledge loop in product life cycle management along the supply chain,
- Collaboration 4.0 and Development of highly skilled R&D and Manufacturing Teams and
- Proving the innovated technologies on selected use cases in real productive environments.

Increasing demands for innovative products and rising competition lead manufacturing companies to design more flexible and efficient production environments. Thus, factory work becomes increasingly knowledge intensive (Campatelli et al., 2016).

Recent developments of digital technologies including social software, mobile technologies, big data analytics, augmented and virtual reality offer promising opportunities to facilitate knowledge-intensive work on the shop floor (Hannola et al., 2018). However, implementing such digital technologies to support knowledge work is not just management fashion, but can sustainably empower daily operations (Leyer et al., 2019).

It is hence the grand challenge of a successful digital (knowledge) work design to improve the current and future work practices of employees by providing digital technologies (Richter et al., 2018). This requires an integrated, interdisciplinary, participative, and agile approach, which allows identifying, analysing, and supporting human work practices in a predominantly digital environment: In such a challenging change process, current work practices must be turned into digitally empowered work practices, while developed digital artefacts must support and transform current work places to enable digital work places in the best possible way.

1.2 The Interlink with WP4 – Skills & Workplaces 4.0 and Smart Collaboration

Within the project iDev40 the work package 4 – where this deliverable is located – deals with Skills & Workplaces 4.0 and Smart Collaboration in ECS Value Chains. The main goals in WP4 are:

- Enhancing Human Capital by Human-centred Knowledge, Skill and Competence Base.
- Enhancing Relational / Structural Capital by Managing Virtual, Remote and High Skilled Teams.
- Enhancing Key Performance Indicators and Complexity Capital by Smart Operations.

Furthermore, the scope is to enhance the capabilities of employees to proper interact with highly automated systems to enable the production of complex products and services by developing and providing digital means of continuous training and education to further promote and foster skills, competencies and decision-relevant knowledge for individual employees and teams, which will be embedded in digitally augmented work places.

The deliverable "Concept of Digitally Augmenting Human Work" contributes to all of the mentioned objectives and is strongly related to the Task 4.1.2: "Digitally Augmenting Human Workplaces".

1.3 Structure of the Document

The developed concept shown in this document is structured into several subchapters:

- The task description includes the motivation, goals and the desired results.
- The use cases definitions determine the requirements to the technical solution on a high level and the context in which they will be implemented.
- The development approach describes also the technical and the organisational approaches to develop and implement the "Concept of Digitally Augmenting Human Work".
- The chapter "Software Demonstrators" describes the current status of the implementation of the use cases.

2 Task Description

2.1 Motivation

It is obvious that the share of knowledge work in production environments is increasing. However, this is not the only reason why more attention needs to be paid to the human factor in production. It is therefore increasingly important to provide workers in a production environment with the best possible support for their knowledge tasks by using modern information and communication technologies. In particular, the technical innovations in terms of Augmented and Mixed Reality offer a great potential to be implemented in relevant applications in connection with the ongoing digitization or digital transformation of production.

Against this background, this task shows how current knowledge-based work processes in production environments can be best supported by Augmented and Mixed Reality technologies. It is outlined in several concrete industrial use cases from the manufacturing domain how human work can be digitally augmented to facilitate knowledge-intensive production tasks.

2.2 Goals

This Report refers to Task 4.1.2: Digitally Augmenting Human Workplaces. The task aims to increase demands for innovative products and to rise competition leading manufacturing companies to design more flexible and efficient production environments.

While recent developments of digital technologies including social software, mobile technologies and augmented reality offer promising opportunities to empower knowledge workers in factories, the challenge of augmenting human work is based on contributing and effectively consuming information that is constantly more complex, combined from multiple sources and types, and is constantly changing.

Supporting human workers with digitally augmented tools means to provide them with an immediate and personalized provision of information, which can be configured according to needs, roles and preferences.

2.3 Results

In this task, a holistic concept for digital augmentation was developed taking advantage of augmented and mixed reality technologies. This holistic concept cares about displaying context-relevant information in the line of sight without media breaks and ensures smooth operation to avoid cognitive overload.

In detail, the following main technical and organisational subtasks were implemented:

- Prepare mechanical CAD data for use in AR environments,
- animate assembly tasks or machinery (robot),
- manipulate the assembly structure of mechanical CAD data,
- create GUIs to support this manipulation,

- create an user interface to handle assembly tasks in HoloLens,
- create a system environment to develop and provide these features and at least
- develop a R&D approach to bring user feedback back into development.

As a next step, this concept will be implemented and evaluated within an industrial demonstrator and will be then documented in Deliverable 4.6.

3 Use Case Definition and Refinement

Together with our partners IFD and HSZG in this task and AVL as an interlink to the WP3 three different Use Cases were defined as a guideline to refine the requirements for the concept of digitally augmenting human work. The use case descriptions are structured in the following way:

- ***Use Case Owner***

  This section describes the company or organization or in other words the use case owner.

- **Current Situation / As-is Situation**

  This section describes the as-is situation in the factory or in the organisation. Those facts are described here that are necessary to understand the relevant facts.

- **Industrial Challenge**

  This section describes the specific problem, challenge and improvement potential in the factory or in the organisation. This problem, challenge and improvement potential refers to the previous described as-is situation and should be understandable by non-domain experts.

- **Target Situation / To-be Situation**

  This section describes the future target situation like a vision of what should be achieved in this project.

- **Expected Impact**

  This section describes the achieved goals of the implementation of this use case on the social or human and business or economic level.

- **Envisaged Solution Approach (optional)**

  This section is optional but can be formulated if the approach is already clear. In the case that there is currently no approach available or in case that the technical approach will be developed in an innovation process this approach can be left off. If this chapter is provided it should be inserted after the chapter "Target Situation".

3.1 Use Case AVL

- ***Use Case Owner***

  AVL LIST GmbH is the world's largest private and independent company for the development of drive systems as well as simulation, measurement and testing systems.

- **Current Situation / As-is Situation**

A design change of a product has, among other things, effects on the manufacture, assembly and maintenance of this product. For this reason, product developers together with the employees from the skill centre develop and revise the manufacturing and maintenance instructions in the form of digital documents. These digital documents describe assembly and maintenance operations with images and text.

- **Industrial Challenge**

  Every time a product is changed in terms of design, the existing manufacturing and maintenance instructions and the illustrations contained in it must be updated manually. Also, the descriptions must be checked for their correctness and applicability. In addition, it must be ensured that the affected employees in production and service are informed about the changes and that the new instructions are easy to understand.

- **Target Situation / To-be Situation**

  The description of manufacturing and maintenance instructions should be created automatically without any media breaks. The affected users should be able to capture and learn these comprehensive instructions with the least possible effort.

- **Envisaged Solution Approach**

  Design data (3D-CAD) together with virtual tests and validations (e.g. installation simulations) should be used automatically for interactive documentation and training material. In order to reduce the learning effort and to increase the experience of documentation, current technologies from the fields of AR (Augmented Reality, for example MS HoloLens) and VR (Virtual Reality) should be used.

- **Expected Impact**

  With improved documentation and training materials, production staff and service technicians can prepare themselves faster and better for new tasks, making them more mobile and more flexible (mobility). Automated documentation changes increase process reliability, thereby reducing manufacturing and maintenance errors.

3.2 Use Case Infineon / mechatronic

- ***Use Case Owner***

  Infineon Technologies AG is a world leader in semiconductor solutions. Infineon Technologies Dresden GmbH is one of the largest production sites of Infineon Technologies AG.

  Mechatronic Systemtechnik GmbH is a successful, fast growing high-tech company headquartered in Villach, Austria developing specialised machines for handling thin, warped and other critical wafers such as ultrathin, TAIKO, MEMS, film frame or eWLB used in the semiconductor processing industry.

- **Current Situation / As-is Situation**

  In the semiconductor industry wafers on which the semiconductor chips are produced must be transported between individual process plants. For this purpose, these wafers are stored and transported in wafer lots in special transport containers. In the process plants, these wafers have to be taken from these transport containers one by one, fed to the process plant (for example an implanter), correctly positioned and finally returned to the transport containers. For this task so-called sorting robots are used. This sorting robot consists essentially of a robot arm which can move the gripping element (end effector) with 6 degrees of freedom. The access position must be taught to the robot manually and is currently done via light gap control. Due to structural boundary conditions, the light gap control and the control of the gripping element is spatially separated, otherwise the light gap is not visible at all. Due to production process changes, or due to the sensitivity of the systems, the positioning of the robot and especially the gripping element must be performed repeatedly. Herein between 80 and 90 positions are programmed for the gripping element.

- **Industrial Challenge**

  Due to the local separation of control and position control, this positioning cannot be done by a single employee alone, or there is currently no viable solution that allows a single employee to perform this configuration work alone. While a trained expert needs around 4-5 hours to complete this configuration process, less experienced people will need up to a week to accomplish this task.

- **Target Situation / To-be Situation**

  With the help of digital assistance systems even less experienced employees should be able to carry out these 80 to 90 positions within one day.

- **Envisaged Solution Approach(es)**

  There are currently several approaches to achieve this goal but it has not yet been decided on this.

- **Expected Impact**

  With the help of digital assistance systems, these adjustments can be made faster and, on the one hand, save time for configuration and, on the other hand, save labour costs. Quick feedback on current positioning reduces frustration tolerance and increases employee satisfaction. For the semiconductor company, machine downtimes are reduced, thereby increasing the productivity of these systems.

3.3 Use Case HSZG

- ***Use Case Owner***

  The Zittau/Görlitz University of Applied Sciences (HSZG) was founded in 1992, has two campuses, one in Zittau and one in Görlitz (Germany) and offers 42 bachelor's, German diploma and master's degree courses in engineering, natural sciences, as well as social and economic sciences.

  The Faculty of Business Administration and Engineering trains economists and industrial engineers. The professorship for production management and logistics participates in several national and European research projects focusing on human-oriented innovations for digital transformation in economy and society together with regional and transregional companies.

- **Current Situation / As-is Situation**

  Information assistance systems capable of digitally augmenting human work, such as MR devices, e.g. Microsoft's HoloLens, are becoming more and more affordable and practicable – even for SMEs. Therefore, HSZG established a digitalization lab to do research and education on digital transformation in economy and society.

- **Industrial or Educational Challenge**

  Future managers and engineers lack hands-on experience and training with these technologies. To make reasonable decisions at management and engineering levels they must be able to judge the usability of technologies in practice, its requirements as well as chances and challenges of its implementation into productive processes.

- **Target Situation / To-be Situation**

  HSZG will provide an MR supported assembly scenario in its digitalization lab that depicts an industrial use case. This will give students/future decision-makers the opportunity to evaluate use, chances and challenges of the MR technology about its implementation, its adaptation, and its effects on the workforce as well as on the manufacturing processes. On the other hand, this MR supported assembly scenario is also usable to conduct empirical studies with students/workers on the general usability of MR applications in production or maintenance to gain insights on the further improvement of such applications.

- **Expected Impact**

  Based on a comprehensive understanding of assembly processes and supporting technologies, especially MR technologies, students of Business Administration and Engineering will be able to make better and less cost intensive decisions regarding digital technologies and digital transformations within companies to improve relevant KPIs for production processes, such as time, quality or costs, bearing in mind its social and ethical implications.

- **Envisaged Solution Approach**

  To develop as realistic as possible trainings and teaching scenarios in higher education, a close cooperation with the industry and the use of similar machinery and technologies at the university is required. Due to the costs of machinery and the lack of a real production process at the university a representative use case must be found and implemented to conduct the evaluating tests of the implementation of MR in assembly scenarios.

4 Research and Development (R&D) Approach

Based on the three use cases, the following main technical and organisational tasks were derived:

- Prepare mechanical CAD data for use in AR environments,
- animate assembly tasks or machinery (robot),
- manipulate assembly structure of mechanical CAD data,
- create GUIs to support this manipulation,
- create a user interface to handle assembly tasks in HoloLens,
- create a system environment to develop and provide these features and at least
- develop a R&D approach to bring user feedback back into development.

4.1 Concept of Digitally Augmenting Human Work

The concept of digitally augmenting human work follows our published research agenda. The whole chapter is already published as a paper (Spitzer et al., 2019). To apply Technology Enhanced Learning (TEL) with Augmented Reality (AR) in industry, a suitable methodology is necessary. This chapter focuses on how to deploy and evaluate AR learning scenarios in industrial environments. The methodology evolved within the two EU projects FACTS4WORKERS and iDev40 and has been improved iteratively. The first step is to investigate the use case at the industry partner. Then the appropriate concept is defined. The next step is to develop a first prototype. This prototype is then improved during several iterations according to the feedback of the industry partner. When the prototype reaches an appropriate Technology Readiness Level (TRL), a final evaluation is carried out to verify the software artefact against the gathered requirements. Figure 1, which summarizes the research agenda, is already published by Virtual Vehicle in Spitzer et al., 2019.

Figure 1: Research agenda for AR in industry (own figure)

We developed a research agenda to plan, conduct and evaluate TEL AR projects in industry. In iDev40, we are developing an AR-based assembly support system prototype in a special purpose engineering domain.

In the first phase, an on-site visit at the industry partner is necessary to gather the real-world context of the use case. Current processes and challenges are identified using interviews and by observing users from the target group. Another important aspect of the on-site visit is to get into direct contact with the workers to build trust and to involve them in the development of the TEL AR prototype.

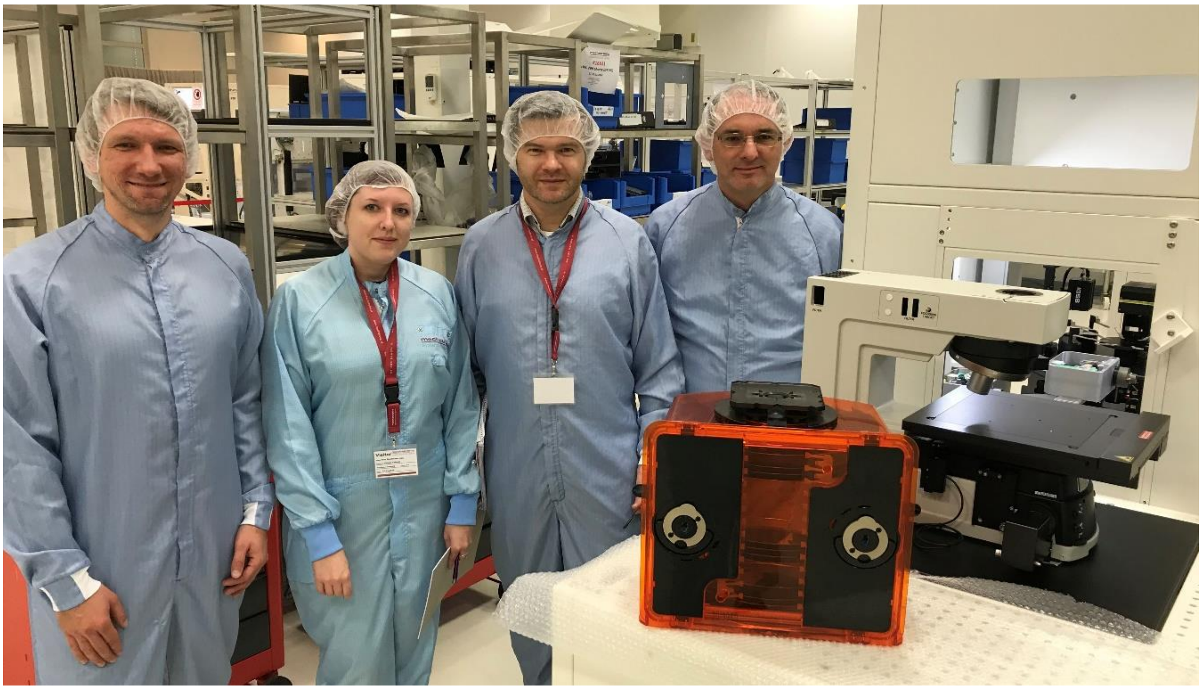

Figure 2: Site visit at Mechatronic Systemtechnik GmbH (own figure).

The second phase is a didactical concept. In iDev40 we are using 3D animations to show the assembly workers assembly instructions. In contrast to printed or digital manuals and assembly videos, the information is presented in 3D to the user.

In the third phase the AR prototype will be deployed at the industry partner and will be improved iteratively according to the feedback of the industry users. The last phase is then a final evaluation.

4.2 System Boundaries and Constraints

We decided to use state-of-the-art AR smart glasses (Microsoft HoloLens) to implement the use cases. The aim of this project is to deploy TEL with AR in industry settings. Additionally, a web-frontend is developed as an alternative. To show the features of the developed demonstrators we are using the construction, production and assembly of a Lego® Technic planetary gear. This approach has proved to be successful in our earlier research since it is very difficult to get approval to publish real-world engineering data of the industry partners (Spitzer and Ebner, 2017).

4.3 Agile Software Demonstrator Development

We chose this approach to deliver first software demonstrators as fast as possible (Beck et al., 2001) Fast demonstrators are a well-suited basis for discussion. This approach ensures that we understand the challenges of the industry partner well and the prototype will solve them. Therefore, misunderstandings or wrong information transfer between the industry partner and the research organisation are identified very early in the project by providing fast demonstrators and by gathering feedback of the industry partners very early in the project.

4.4 Continuous Integration and Deployment (CI/CD)

Continuous Deployment describes the process to enable the release of working software at any time and any IT infrastructure automatically (Duvall et al., 2007).

We use the Continuous Integration and Deployment (CI/CD) approach to ensure a running demonstrator in every stage of the project. Whenever new code and features are added to the demonstrator a rebuild and deployment is triggered to update the running software demonstrator.

4.5 Build Environment

To follow the CI/CD approach the following processes were established. We use GitLab1 on premise to commit our source code. With every code commit we trigger a rebuild of the software demonstrator. Figure 3 shows our CI/CD pipeline for the web-based demonstrator. After a new commit of the web application to GitLab, all tests are triggered automatically and if they pass, the code is then transferred to a docker2 container. The docker container exposes the web application automatically to fulfil the CI/CD pattern. With this environment we always have a running demonstrator available.

[1] https://gitlab.com
[2] https://www.docker.com/

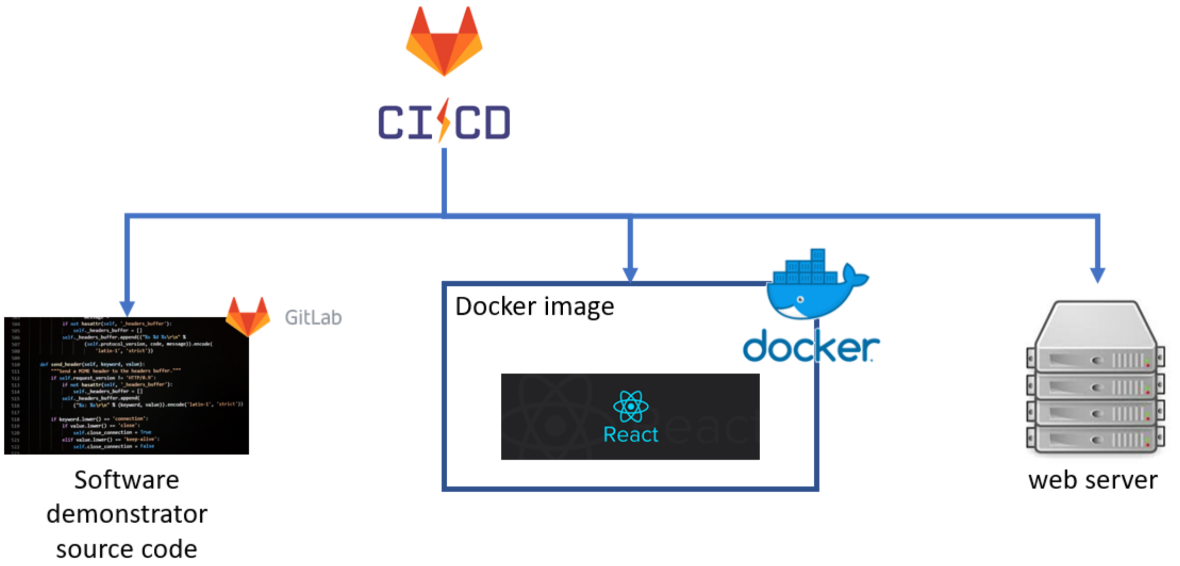

Figure 3: CI/CD environment for the web-based demonstrator (own figure).

The CI/CD process for the web interface is divided into several steps. Figure 4 shows the involved steps of the CI/CD pipeline. In the build phase, the web project is built with webpack. Then all the tests are executed to ensure a good quality of the committed code. As a last step the project is packed into a docker container and deployed to the web server.

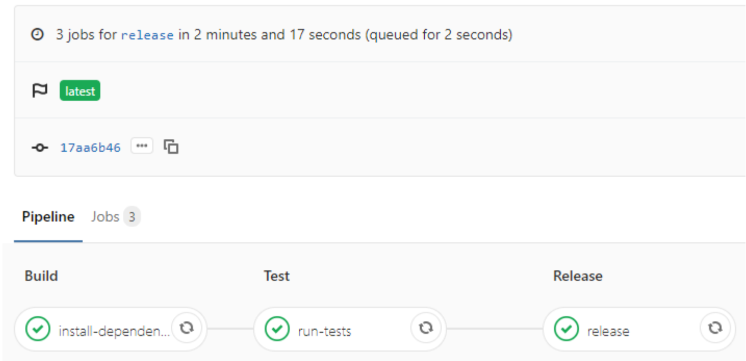

Figure 4: Steps of the CI/CD pipeline (own figure, GitLab screen shot)

Listing 1 shows the YAML file which is used to setup the CI/CD environment for the web interface.

```
image: docker:latest

services:
  - docker:dind

variables:
  DOCKER_DRIVER: overlay

stages:
  - build
  - test
  - packaging
  - release

cache:
  paths:
    - node_modules/

install-dependencies:
  image: node:lts-alpine
  stage: build
```

```
  script:
    - yarn install
  artifacts:
    paths:
      - node_modules/
  tags:
    - docker
    - react
    - node

run-tests:
  image: node:lts-alpine
  stage: test
  script: yarn test
  tags:
    - docker
    - react
    - node

packaging:
  image: node:lts-alpine
  stage: packaging
  script: yarn build
  artifacts:
    paths:
      - build/
  tags:
    - docker
    - react
    - node
  only:
    - master

release:
  stage: release
  before_script:
    - docker version
    - docker info
    - docker login -u gitlab-ci-token -p $CI_JOB_TOKEN $CI_REGISTRY
  script:
    - docker build -t $CI_REGISTRY/$CI_PROJECT_PATH:$CI_COMMIT_SHA-staging -f Dockerfile-
staging .
    - docker push -t $CI_REGISTRY/$CI_PROJECT_PATH:$CI_COMMIT_SHA-staging Dockerfile-staging
    - docker run --name idev40-avl-staging -d -p 443:443
$CI_REGISTRY/$CI_PROJECT_PATH:$CI_COMMIT_SHA-staging
  tags:
    - docker
    - react
    - node
  only:
    - release
```

Listing 1: GitLab CI/CD YAML file for the web frontend (own listing)

For the HoloLens demonstrator we use Jenkins[3] to trigger a rebuild of the HoloLens application. Since the build process for HoloLens applications is more complex, the features of GitLab CI are not enough to ensure a smooth build process. The build process for Microsoft HoloLens works as follows (Microsoft):

- Build a Universal Windows Platform (UWP) app.
- Open the resulting Visual Studio project.
- Build and deploy the Visual Studio project.

Figure 5 shows the CI/CD pipeline for the HoloLens AR application. We build the HoloLens application in Unity and a code commit to GitLab triggers a Jenkins build. The code is pushed to a Windows-based Unity server where the HoloLens UWP application is built automatically.

[3] https://jenkins.io/

After the build is finished, the UWP application is deployed to the HoloLens device automatically.

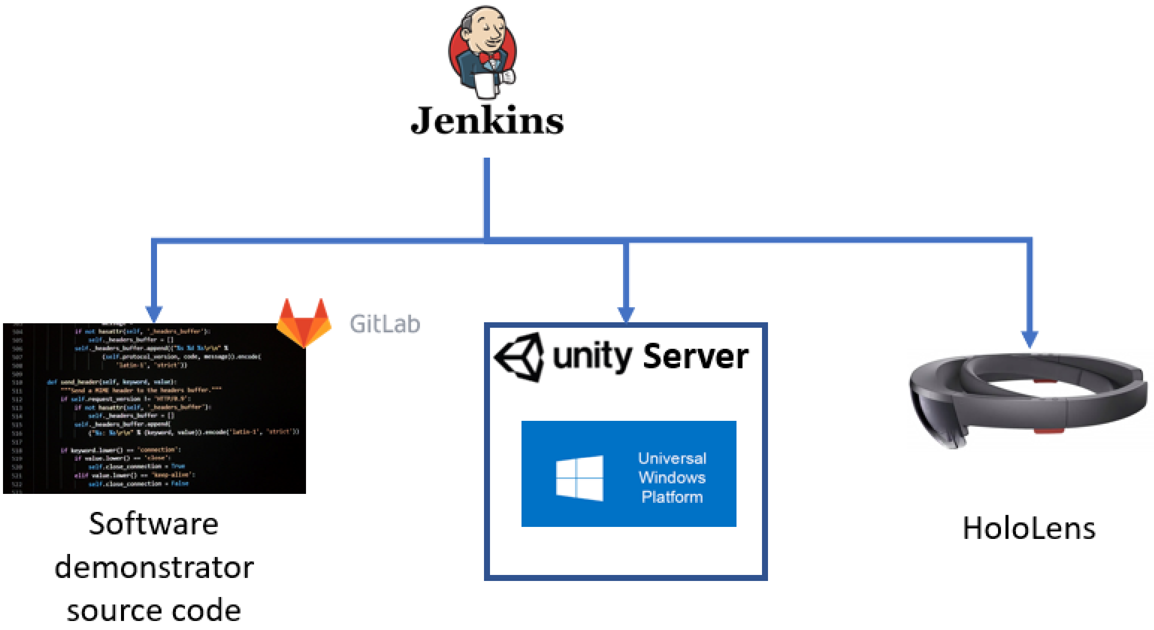

Figure 5: CI/CD Environment for the AR Demonstrator (own figure).

4.6 Runtime Environment

The developed web-based demonstrators are hosted on a Linux server with installed Docker environment. With every code commit the demonstrator is rebuilt and deployed on this server. Figure 6 shows the system architecture of the runtime environment. We use Debian[4] Linux as operating system with a running Docker instance. The web-based demonstrator, programmed in JavaScript, is running as a docker container on this server.

Figure 6: Runtime Environment (own figure).

The AR demonstrator is running on the Microsoft HoloLens as a UWP application. Figure 7 shows the Microsoft HoloLens.

[4] https://www.debian.org/

Figure 7: Microsoft HoloLens (Wikimedia - Ramahololens).

4.7 Technical Risk Analysis

A big challenge in this field is to connect engineering software with AR and web-based systems. The Microsoft HoloLens is using a Game Engine (Unity) as a development environment and the challenge is to exchange game-based 3D formats with classical engineering data (CAD). A first proof-of-concept was implemented as a feasibility study. We can connect proprietary engineering formats with the 3D Engine Unity to show the Engineering data in AR smart glasses. A big challenge in industry settings is to connect brown field systems to new technologies and/or devices.

5 Software Demonstrators

We developed two software demonstrators. The first demonstrator is a web-based system to show and manipulate CAD data, engineering bill of materials (EBOM) and manufacturing bill of materials (MBOM). The web-based demonstrator is implemented with Facebook's web framework React[5]. React is a JavaScript library for building user interfaces. The second demonstrator is an AR demonstrator for the Microsoft HoloLens implemented with Unity[6].

5.1 AVL

One important goal of the project is to provide a generic approach to bring engineering data to AR applications. The solution should be independent of any proprietary software product or vendor. To achieve this goal, open CAD file formats as STEP are used. The STEP file standard is defined in ISO 10303-21:2016[7]. Most of the proprietary CAD tools can export their CADs in this file format. Additionally, we decided to use open source software tools to achieve the conversion process. The browser-based web application is built with the React JavaScript framework. For the HoloLens we use the proprietary game engine Unity. We use the STEP format to attach to the CAD system of the industry partner. Additionally, we connect their ERP/PDM system to extract part and assembly information. In the first stage we are using an in-house REST service mock system to not affect the real-world systems in production. The CAD kernel takes the STEP export and converts it to mesh format. The mesh is then used to show 3D geometry in the browser and in the HoloLens.

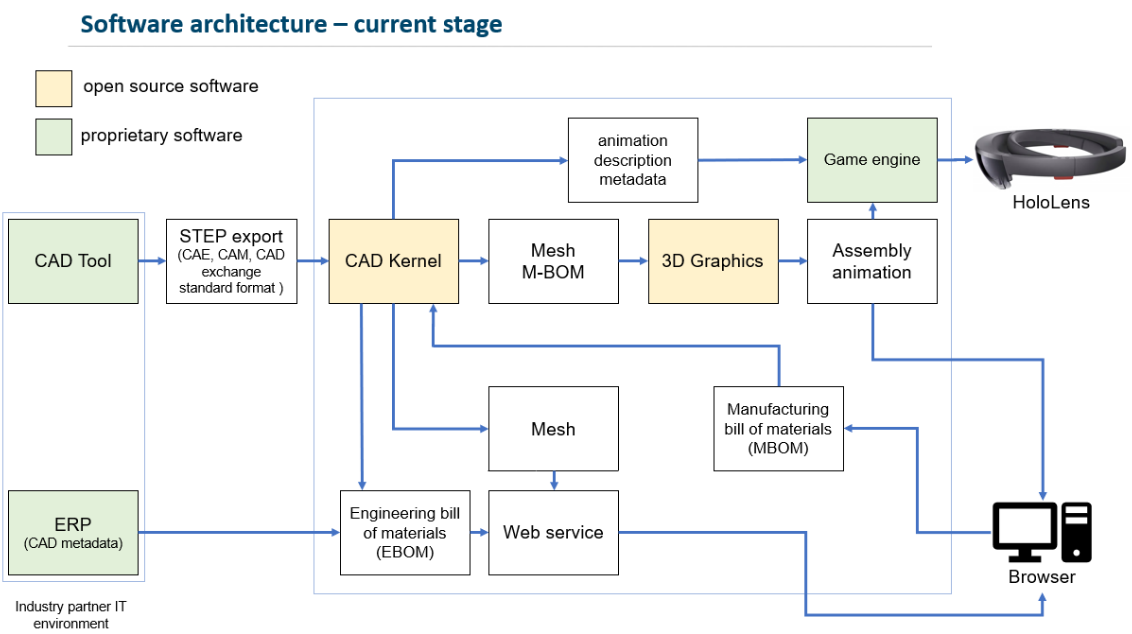

Figure 8: Software Architecture (own figure).

[5] https://reactjs.org
[6] https://unity.com
[7] https://www.iso.org/standard/63141.html

5.1.1 Web-based Demonstrator

The assembly planning engineer will use the web-based demonstrator to manually map the engineering bill of materials to the manufacturing bill of materials. Additionally, the assembly planning engineer can investigate the assembly animation generated from the manufacturing bill of materials. This assembly animation is then presented to the assembly worker to help him to assemble the product correctly. A typical scenario is that the assembly planning engineer logs into the system to investigate the engineering bill of materials and the appropriate CAD model in the web application. Figure 9 shows such a typical scenario. Then the assembly planning engineer creates a MBOM by dragging-and-dropping the parts and assemblies in the tree on the right-hand side. This tree encodes the assembly order of the product. When the assembly planning engineer has finished work, the system is automatically creating the assembly animation which will be shown in the web frontend. Figure 9 shows a screenshot of the web demonstrator.

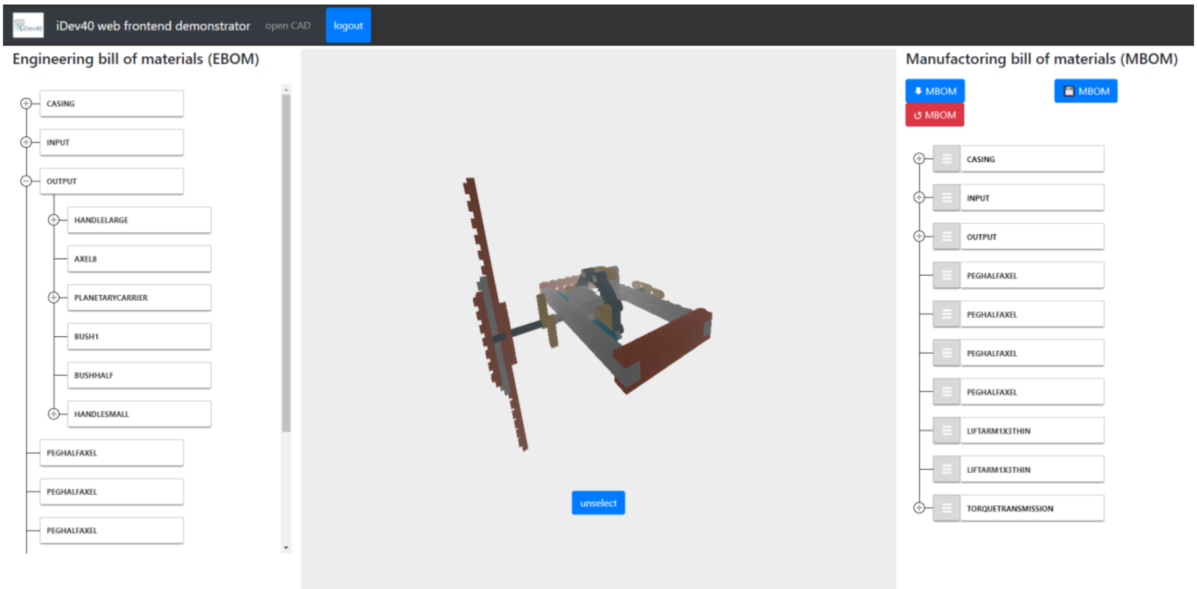

Figure 9: Web-based Demonstrator UI (own figure).

5.1.2 AR Demonstrator for Microsoft HoloLens

The following figure shows the AR for Microsoft HoloLens.

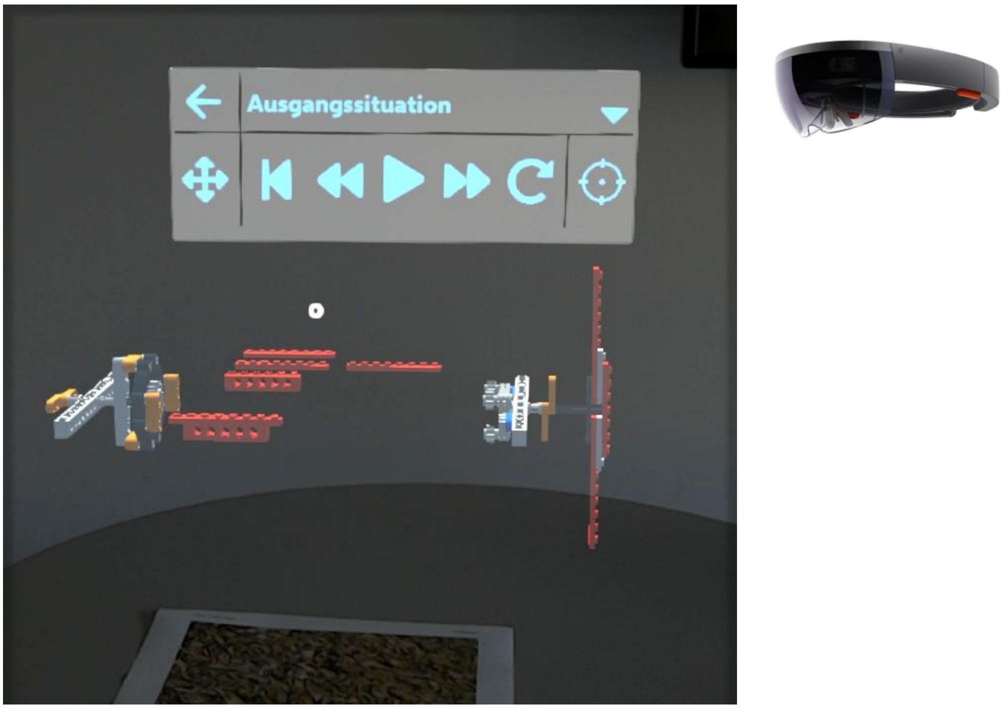

Figure 10: AR Demonstrator for Microsoft HoloLens (own figure)

With the HoloLens demonstrator the assembly worker sees the assembly instruction in 3D space. Additionally, the changed parts (between hardware revisions) are highlighted to identify changes in CAD data. The animations can be paused, forwarded and repeated. A big advantage of this approach is that the assembly instructions can be investigated from several viewing angles by walking around the hologram. This is not possible with paper-based manuals or video instructions. The used 3D model is shown in Figure 11.

Figure 11: Lego Planetary Gear 3D Model (own figure)

5.2 Infineon

The first step was to perform a feasibility study. We decided to use a Lego® Technic wafer sorter as a demonstrator at our research centre to implement a first working software and hardware demonstrator. The reason to use Lego® Technic is that it is not possible to get the real wafer sorter for our office. Fortunately, it is not necessary to build the demonstrator with the real robot. The software interfaces are generic by design and could be switched to fit the real-world use case with reasonable effort. Figure 12 shows the Lego® Technic wafer robot demonstrator. The goal of the robot is to transport wafer (CD-ROMs) from one box to another box. To control the robot remotely a Raspberry Pi is used to connect the robot to our network.

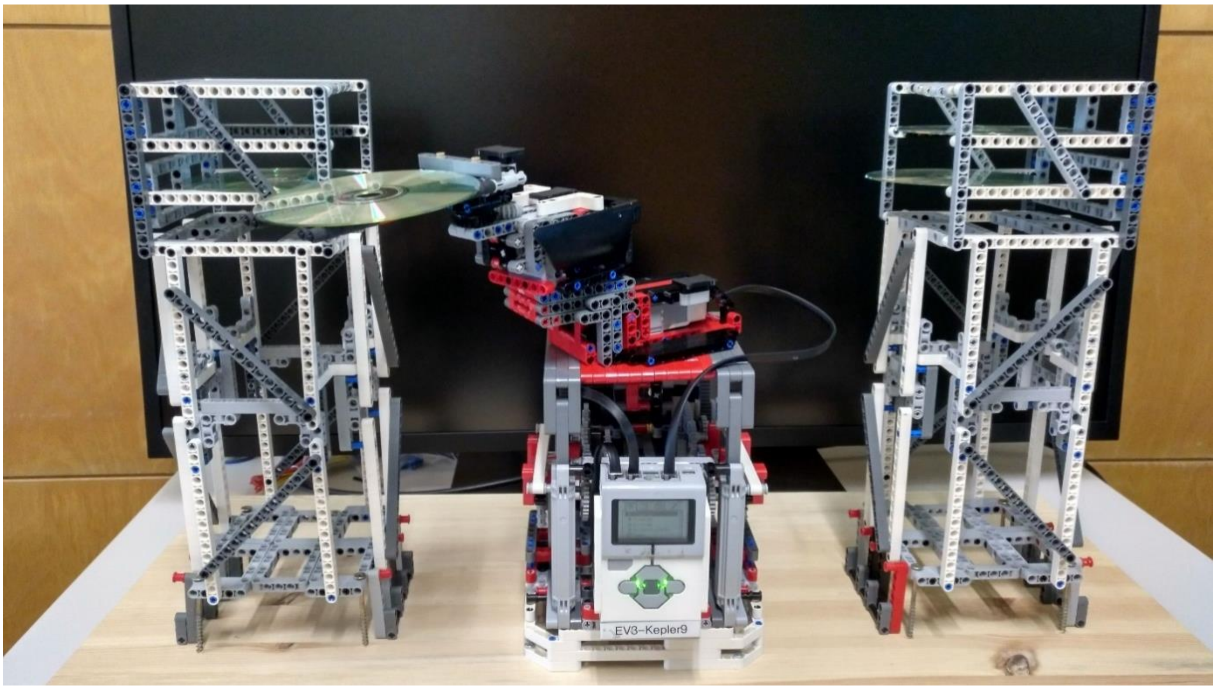

Figure 12: Wafer Sorter Lego Model (own figure).

The next step was to create the 3D model of the Lego® wafer sorter robot. The 3D model is used to build a software demonstrator which shows the robot arm movement on a monitor and the HoloLens. Figure 13 shows a screenshot of the 3D model.

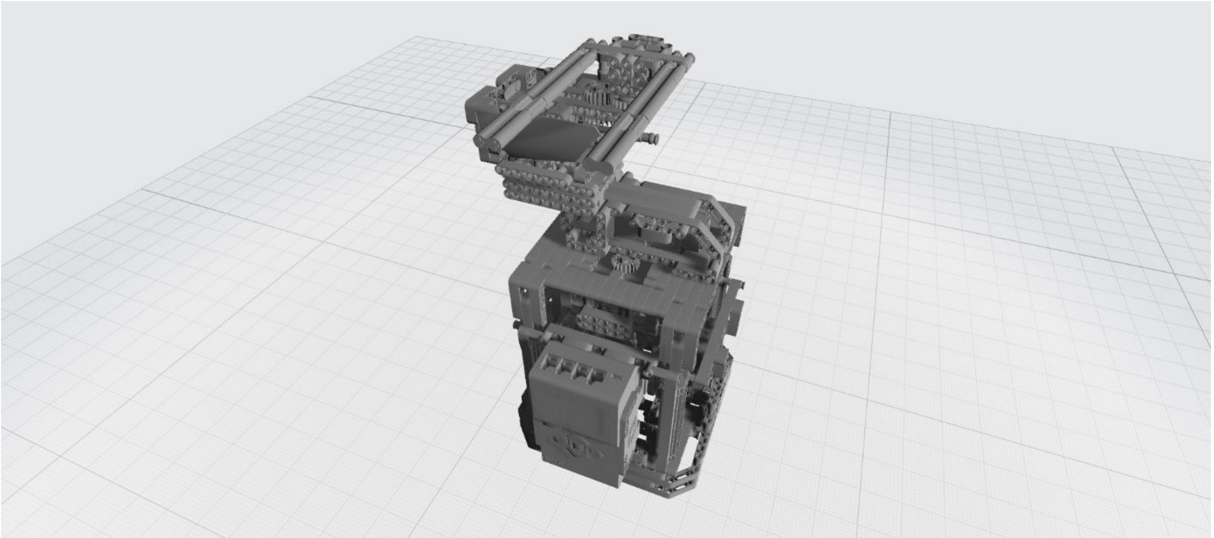

Figure 13: 3D Model of the Robot Arm (own figure).

After the 3D model was created an appropriate 3D engine was selected to visualize the robot arm movements. We use the 3D engine Processing[8] because this engine is available as open source and fits our requirements to be able to visualize the robot arm movements on screen. Figure 14 shows the 3D model of the robot arm imported to the Processing 3D engine. The circles indicate the movement range of each robot joint. This information is very helpful to know the area of operation of the robot arm. The next step was to move and rotate the 3D model according to the real movements of the robot. Therefore, we attached sensors on the real robot arm to get the current position of the robot arm.

[8] https://processing.org

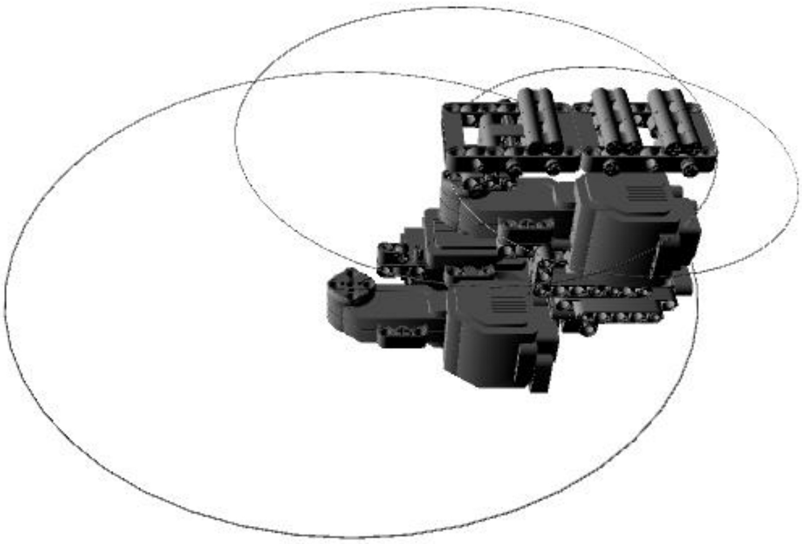

Figure 14: Processing Engine (own figure).

The gathered data of the sensors is used to transform the 3D visualization and model according to the real position of the robot arm. Figure 15 shows the involved interfaces. The sensors are connected via I2C to a I2C multiplexer. This multiplexer is connected to the Raspberry Pi. The Lego® motors are connected to the EV3 main block which is connected to the raspberry pi via USB. A TCP interface was developed to connect the raspberry pi to any kind of control device and unit. In the current stage we can control and monitor the sensors and motors with a personal computer. The next milestone is to connect the Microsoft HoloLens to the system.

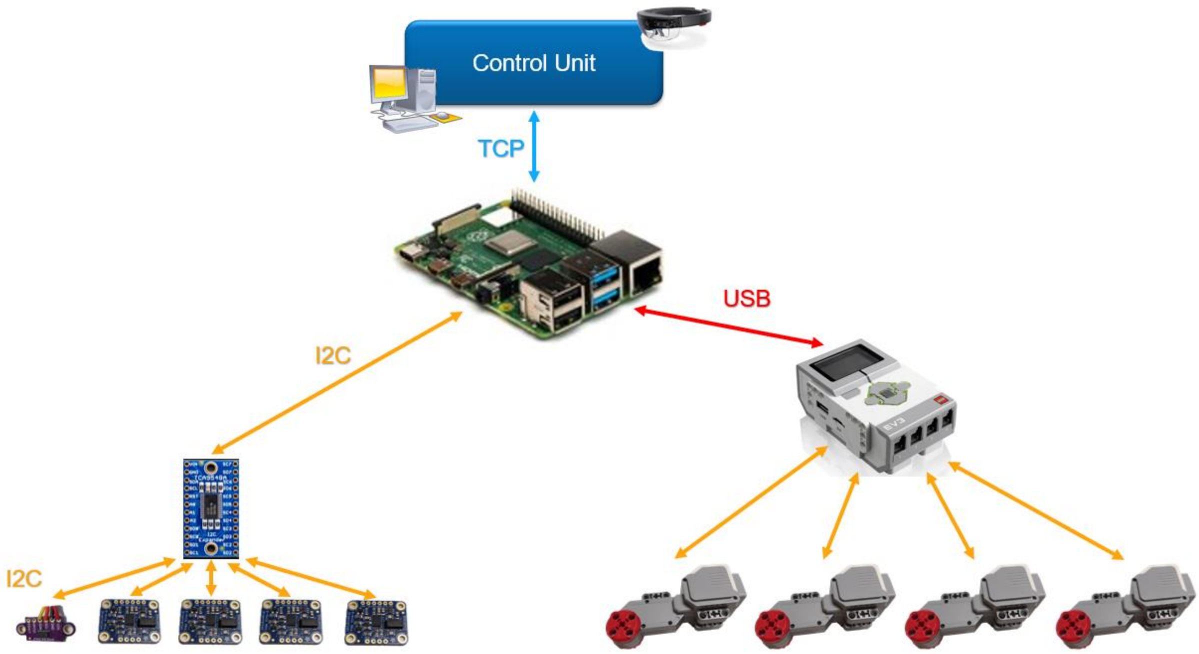

Figure 15: Interfaces (Wikimedia).

With the described demonstrator a visualization of the robot arm can be shown in 3D which follows the real robot arm movements. Figure 16 summarizes the functionality of the demonstrator. A movement of the real robot arm is detected by the attached sensors. The values are then transmitted to the 3D engine running on a computer or the HoloLens. The 3D model will move and rotate according to the transmitted sensor values. Hence, the 3D model follows the movements of the real robot arm. This concept can be applied to the real-world use case with reasonable effort provided that the accuracy of the attached sensors is high enough.

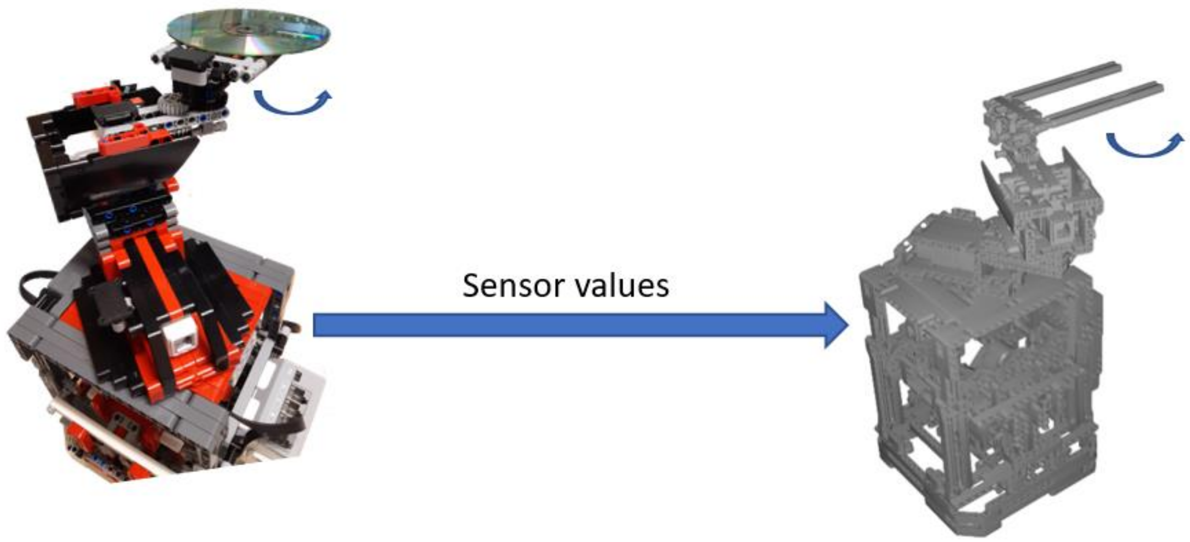

Figure 16: Infineon Demonstrator (own figure).

5.3 HSZG

The HSZG use case covers the evaluation of the HoloLens demonstrator of the AVL use case. One main research question is the effectivity of a 3D animated assembly instruction shown in the HoloLens. Therefore, three different types of assembly instructions are developed and compared within the study. Within the study, a paper-based manual with pictures, a video instruction and the 3D animation instruction are tested, all based on the latter (Figure 17). The subjects must then assemble parts of the Lego® Technic planetary gear correctly.

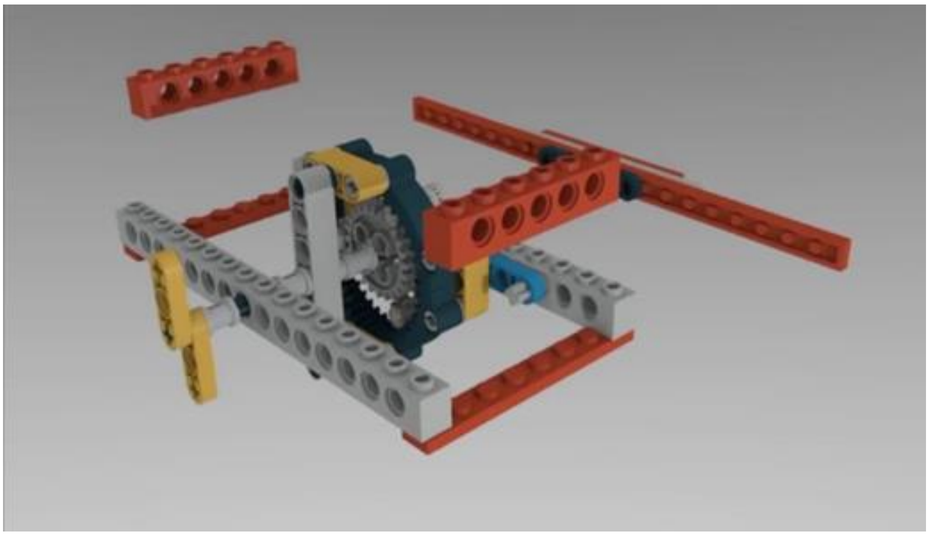

Figure 17: Screenshot of the 3D Assembly Animation (own figure).

Several KPIs such as time and quality are evaluated but also soft factors such as stress, monotony or strain. So far, a pilot study of the evaluation has been conducted, that will be improved and applied at the AVL use case in a next step. These will then be reported in detail in the final Deliverable 4.6 "Evaluated Augmented Work Demonstrator" of Task 4.1.2. In the following, the pilot study and the current concept of the evaluation are described.

The purpose of the study is to draw conclusions from the used type of manual and the characteristics of its users to production and product related KPIs as well as to aspects of occupational psychology. Therefore, the study is designed as an experiment (Brosius et al., 2012), where the independent variable is the type of instruction manual (paper, video or AR), and the dependent variables are: assembly time, quality of the assembled product, comprehensibility, requirements (mental and physical), stress level and success assessment.

Hence, the necessary data are collected at three points: before, during, and after the experiment itself. First, based on socio-demographic characteristics, on personal preconditions as well as on previous skills and knowledge, e.g. with assembly tasks in general or with AR, that possibly have an effect on the dependent variables, the test persons are distributed parallelly into three groups based on the type of instruction manual. This information is gathered by a self-assessment of the participants a priori:

- Age,
- gender,
- course of study and semester,
- experience with MR,
- experience with assembly tasks in general,
- experience with Lego® (Technic),
- fine-motor skills,
- spatial thinking and
- physical constraints (e.g. visual impairment).

In this way, it is assured to have as similar groups as possible. These characteristics of the test persons are surveyed before the experiment. After their distribution into these groups each test person receives the same instructions, stating the goal to assemble the parts of the Lego® Technic planetary gear correctly according to the manual. Only the test persons using the AR instructions will play the demonstration video once to get used to the control of the head-mounted display (HMD). During the assembly task the researchers take notes on the following dependent variables:

- Used control possibilities of the manual (if using the AR manual),
- assembly time, assessed over different categories of activities (e.g. assembling, idle, etc.) (Robinson, 2009) and
- quality of the assembled product.

After the task, the participants are asked again to give answers to the independent variables during a self-assessment:

- Comprehensibility,
- requirements (mental and physical),
- stress level and
- success assessment.

Where possible, well established rating scales from the field of sociology and psychology are used for the self-assessment – e.g. based on the Big Five Inventory (Rammstedt et al., 2014).

For the purpose of the pre-study six test persons where randomly distributed into the three groups – due to the small group of participants a parallel distribution into the groups made no sense. Due to the uncomplicated availability at the HSZG, students were asked to participate in this stage of the study (Figure 18).

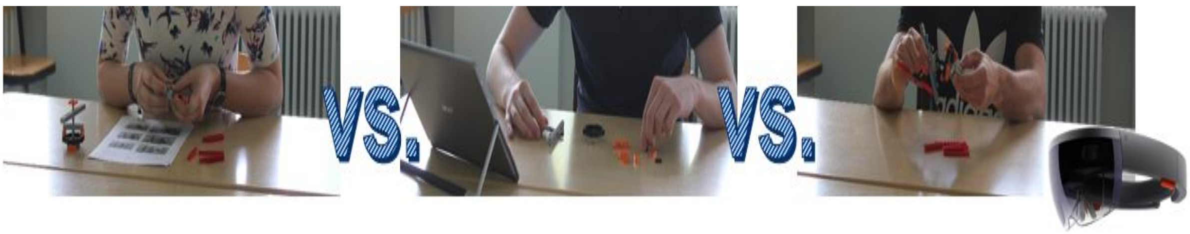

Figure 18: The Three Types of Assembly Instructions during the Pilot Study (own figure).

During the pre-study phase, several possibilities of improvement of the study design and set-up where identified:

- The initial instructions on the procedure of the experiment will be given in written form or read out instead of a freely oral form to give every participant the exact same information.
- Some question items need clarification to be understood by the participants immediately.

- Instead of randomly placing the Lego® parts before the experiment, it probably makes sense to group them by components to come closer to a real industrial scenario.
- Setting a time allowance for finishing the assembly could also add to a more realistic scenario.
- To ease the notation of observations of the researchers during the experiment the observation form should be further standardised and/or the experiment should be taped for analysis at a later point and in more detail. This could also reduce stress of the participants due to fewer physically present observers.

Figure 19 depicts the procedure of the study.

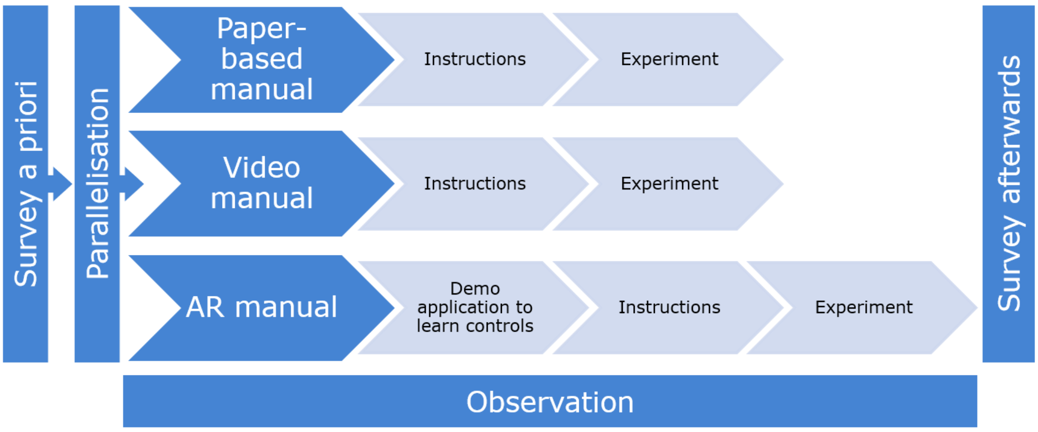

Figure 19: Procedure of the Evaluation Study (own figure).

In addition, further aspects that might be relevant to draw conclusions on the effectiveness of the AR demonstrator aroused:

- The current level of fitness of the participants taking part in the experiment could play a role on the performance.
- Personal traits such as e.g. diligence might have an impact on the performance with different manuals as well.
- The ability of multitasking might influence the performance with different manuals as some of them require interacting with digital controls (video or AR).

However, as so far it is planned to assemble the planetary gear just once, it is not yet possible to draw conclusions on the lasting of a learning effect with different manuals. Besides, it is not possible to test the flexibility of the workers using different types of instructions when minor changes in the assembly manual occur after some period of time. These aspects should be considered for later further developments of the study design.

During the next steps and towards the final Deliverable 4.6 the above-mentioned improvements will be implemented into the evaluation study of the AR demonstrator with workers. Additionally, this scenario and the evaluation method can be adapted for teaching scenarios for industrial engineers at the digitalization lab of the HSZG.

6 Conclusion

Implementing augmented and mixed reality in industrial use cases can have both theoretical and practical implications. For instance, digitally augmenting human work can enable context-aware access to process-relevant information and knowledge at the shop floor and allow cutting service and/or production times, while at the same time increasing product and process quality as empowered employees can make better-informed decisions.

Context-relevant information displayed in the field of view of the worker without media breaks, and seamless interaction across different IT tools becomes crucial for smooth operation and avoidance of cognitive overload. This will obviously generate not only a technical but also a social impact in factories.

The work documented in the present text, is highly promising to improve the worker situation in the factories as well as the competitiveness of the European Industry and generates substantial input to the following relevant topics:

- Supporting workforce trainings & learning processes.
- Enable training scenarios for virtual and remote teams.
- Supporting flexible production environments (especially small lot sizes).
- Keeping the human in the loop (facilitate semi-automated production environments, i.e. digitization of processes).
- Better understanding of the human and organizational role in factory digitalization.
- Strengthen the human role in the digitized production processes.

A concept of digitally augmenting human work was developed and published as a paper (Spitzer et al., 2019).

After the development of the concept, first demonstrators have been implemented.

As a next step the demonstrators will be improved iteratively and evaluated within an industrial demonstrator according to the developed concept.

The progress will then be documented in Deliverable 4.6.

7 List of Abbreviations

Abbreviation	Meaning
AR	Augmented reality
CAD	Computer-aided design
CI/CD	Continuous integration / Continuous deployment
EBOM	Engineering bill of materials
ERP	Enterprise resource planning
IT	Information technology
MBOM	Manufacturing bill of materials
PDM	Product data management
R&D	Research and development
STEP	Standard for the exchange of product model data
TEL	Technology-enhanced learning
UWP	Universal Windows application

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