Augmented Reality in the Pharmaceutical Industry-A Case Study on HoloLens for Fully Automated Dissolution Guidance

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***Abstract*—Augmented Reality (AR) enriches the physical world with virtual objects thrown, such as head-mounted displays. These head-mounted displays are commercially available and enable a hands-free experience.**

There are many fields where AR improves working processes, especially in industry 4.0. It plays a vital role in the digitization of operating procedures. In the pharmaceutical industry, besides manufacturing processes, lab tasks can benefit from this technology. This project aimed to create and evaluate an application for an automated dissolution bath used to simulate the dissolution profile of finished dosage forms, like tablets, capsules, or similar. We used different modalities of targets to place virtual objects in the correct position. In this thesis, we exploited the Vuforia Engine 9.6 in Unity with model-based target and image-based target to evaluate which is more convenient and reliable in a lab environment.

The model-based target was able to detect two out of four objects. With an image-based extended target, we could catch all object positions simultaneously as they are stationary and not movable. It shows the potential of area targets in this field. Finally, we evaluated the user scenario and evaluation in immersive analytic. We found out that AR has a potential for complex experiments, but short periods and specific tasks due to wearing experience and side effects like blurry eyes. The system was tested for three weeks by four users, and there was no significant reduction in the error rate.

Keywords:: **AR, pharmaceutical industry, Training, Evaluation**

***Index Terms*—AR, Pharmaceutical Industry, Guidance, Evaluation**

I. Introduction

WITH augmented reality (AR) it is possible to "step through the glass" into a computer-aided and enriched world [1].

In 1997 there was an initial need for Augmented Reality (AR), with the complex design of Boeing 747 wiring and construction with standard operating procedures (SOP) reached its limit. The team of Boeing enhanced the manufacturing process with AR that enabled the team to build these modern planes. Position to drill and connections for wires were augmented through head-mounted displays (HMD) with see-through glasses that augmented the reality with instructions. AR was a major advantage for production. [1]

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This see-through glasses (STG) enable to blend the real and the virtual world in one space, called mixed reality (MR) and includes beside AR also Augmented Virtuality (AV), see Fig. 1 [2].

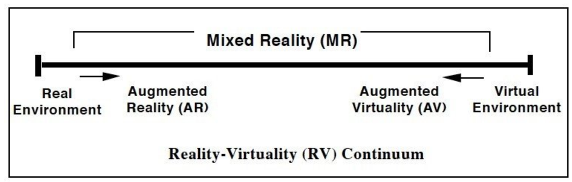

Fig. 1. Mixed reality continuum from left real world to right completely virtual environment [2].

MR has a great potential for different fields of research, and this topic is young. The first paper that defines what AR includes was published in 1997 by Azuma and defined:

1) Combines real and virtual
2) Interactive in real-time
3) Register in 3D

With different methods, the mentioned requirements are achieved: Visual displays, handheld displays, projected displays, video see-through (VST) HMD, or optical see-through (OST) HMD [3]. Threw enhanced sensory perception and embodied interaction, these immersive systems rapidly matured to bring commercially successful devices and applications to mass-market [4].

Through that and other factors, MR is a fast-growing market, and the compound annual growth rate is expected to be about 44 percent from 2021 to 2028; this means a revenue forecast of 340.16 billion USD in 2028 [5]. This market is even pushed by the Corona crises when traveling was hard to organize, and video calls are on the daily order, especially in the healthcare sector [6].

Through this market trend, Microsoft invested a lot of effort to establish itself in this sector, which also needs a lot of computing power. One of the most popular OST HMD designed by Microsoft for MR is HoloLens that was initially introduced in 2016.

Development in the tech industry is rapid, and HoloLens 2 was already released in 2019, equipped with a better camera, higher resolution, larger field of view, and more efficient gesture recognition.

To enable these technologies for companies without the required programming skills new approaches get on the market that deal with this lack of experience [7].

New applications developed by Microsoft, e.g., Microsoft Dynamics 365 Guides or by PTC, e.g., Vuforia Enterprise Suite, enable the operator to design instructions step by step, adding CAD files and targets for correct placement. Microsoft Dynamics 365 Guides also helps to analyze the progress and efficiency of the process through lead times, times per step after using the instruction.

It enables companies to implement AR in their working processes efficiently, and there are a lot of other opportunities besides manufacturing itself [3].

Currently, the primary users are service companies and machinery and plant engineering that are using AR mainly for manufacturing. Still, there is already a trend also in the pharmaceutical industry like remote assistance, and knowledge transfer [8], [9]. For example, in Germany, nearly three-quarters of the companies use MR, but the main issue is still the fear of safety leaks[9].

Besides the fear of safety leaks in the pharmaceutical industry, the importance of good processes and documentation (GxP) is essential. Therefore the users should select applications that benefit most from the use of AR [8].

For a good user experience, target recognition is crucial for AR experience; companies and research institutions designed different targets to fit different use case needs. Palmarini 2018 divide AR-tracking into the following categories: Model-based, Features-based, Marker-based and others [10].

Ninety percent of the tracking in maintenance cases are done by the first three of them, and of these, 52 percent are established with markers [11]. Also, in other instances, markers are widely used.

Markers are most common in assembly tasks, and many researchers use them due to their accuracy, flexibility, and ease of use [12], [13], [14]. The wide use of markers is not just in prototyping the case; also Microsoft Guides mainly uses markers for anchoring objects. The other techniques without markers are more advanced alternatives because markers don't need to be placed in the environment or on each part [15].

For model-based recognition, CAD files are trained to detect the object afterward from different angles and positions. Thus, not just the size and proportion are essential, also textures and colors. Feature-based recognition is the most advanced and versatile field of detection, with filters features, points of interest are detected, for example, kernel filter. This approach is widely used automobile industry for autonomous driving to see cars, road symbols, pedestrians, or traffic lights.[15]

Another exciting technique for object placement is area targeting by PTC. By scanning the environment before with a light almplification by stimulated emission of radiation detection and ranging (LIDAR) scanner, the HMD can recognize the area by the scan. Area targets are interesting for static objects like rooms, labs, or even environments at the scale of an airport. Many papers describe tasks for AR in a testing environment, and now it is crucial transferring these opportunities to applications[16]. Especially in the pharmaceutical industry, this advantage of AR can have a considerable impact.

From the 1990s until today, there is no reduced research and development time for drugs in the pharmaceutical industry, but AR already showed benefits for transferring analytical procedures to other locations remotely [8], [16].

The first main goal was to design an AR application for a task in the pharmaceutical development team by using HoloLens 1. This paper uses OST HMD as they have the benefits that the user can still see everything. Furthermore, HoloLens does not need external computing, and the operator can work hands-free. To evaluate the impact and opportunities of AR in pharmaceutical development, we developed an application for a fully automated dissolution apparatus from SOTAX. Different tracking methodologies were implemented and tested, with Vuforia Engine 9.6 in Unity, in the lab to make the application as convenient as possible. At the moment, this is all tested in a non-GxP environment due to data and privacy regulations.

II. Methods for application

A. Evaluation of Usecase

To evaluate the chosen use case, we used the evaluation framework for Immersive Analytics (IA). IA uses AR to visualize data to make it better understandable. In the grand challenges in IA, Barret Ens et al. designed a framework to evaluate system performance and how these attributes can be measured [16].

It has to be evaluated how pharmaceutical employees can benefit from AR in a lab environment. AR tasks can lead to a reduction of costs, time, and errors, but not for every study [17], [18]. In addition, the task needs a certain complexity, and the handling of the new operating system needs to be designed well to see improvements. [18]. When designing an application, it is vital to take into consideration who the target user is and what kind of tasks they likely pursue [19].

B. Use Case

For the development of pharmaceutical treatments with tablets, capsules, and similar finished dosage forms(FDF), the dissolution profile is essential to understand the absorption of the active pharmaceutical ingredients (API) by the body. Therefore, an automated dissolution apparatus is used to analyze FDFs in different media that simulate the gastrointestinal tract.

The system consists of four main parts: a dissolution bath with six vessels, a multi-dosage unit, a photometer, and a sample collector. They are all placed on the lab table like figure 2 shows.

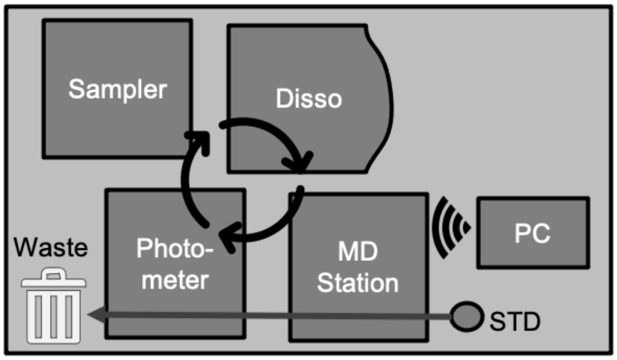

Fig. 2. Setup of the fully automated dissolution. The PC controls the MD station with the microcontroller. The MD station adds new media to the vessels after it is preheated and degassed. Samples are added to the media. The MD station pumps the media with the dissolved API through the filter station; next, the photometer can analyze the filtered liquid or be sampled by the sampler station to analyze afterward. The remaining fluid gets back to the dissolution vessels. When standards are used, the MD station also pumps and filters the standard to the photometer. By this, they are analyzed and afterward disposed to the waste container.

In the next part, the procedure, how the system works will be described in detail. Vessels in the dissolution bath are filled with a defined volume with preheated and degassed media with certain pH and ionic strength.

A stirrer unit or basket attachment mixes the medium until the temperature reaches the set point. In the next step, a tablet dropper or robot adds the FDF to the media automatically. After adding the FDF, samples are pumped through a filter station in the multi-dosage (MD) station to quantify the dissolved API with different analytical methods. Analysis can be online, which means a sample directly is analyzed by a photometer and pumped back, or offline, samples are taken and stored in a sample taker and analyzed afterward with a suitable instrument, e.g., HPLC. At the end of the dissolution, the dissolution media with the FDF is pumped out of the system, and a cleaning process starts. The fully automated dissolution can repeat this whole process up to eight times to analyze a total of up to 36 FDFs.

With multi-dosage (MD) software, a dissolution run is set up in a method. Specific properties are defined in a method, e.g., used port media, media volume per vessel, the slid width of the cuvettes, wavelength for detection, sample volume, sampling time points, or cleaning volumes for vessels and tubing.

A batch is created out of multiple methods to perform numerous dissolution-runs with the defined methods.

Lab associates have to run these experiments infrequently with changing parameters. Therefore an AR application helps the operator to assembly the instrument right and configure the software for the needed investigations.

1) Design method and create batch: For designing a method or create a batch, the application instructs the user through steps to help to set parameters or functions of the automated dissolution. A panel with text and screenshots displays step-by-step instructions. For a better experience, rectangles and circles enrich the screen tho show the users where they need to click. An image target that sticks to the desktop as a reference point is recognised for the augmentation.

C. Prepare instrument

In the prepare instrument scene, the user gets instructions were to add parts, switch valves or put tablets. This was once tried with object detection and once with an image target that was calibrated to the room. For the calibration of the lab, a spatial map was recorded via the device portal. This spatial map in .obj was added into the unity project under the image recognition. In Unity, a position correction was done by changing the angles and position of the spatial map until the spatial map matched the real lab environment. This was afterward used to place the CAD files of the equipment and the information for the user. This is very similar to an area target, just working with an image target for recognition. In the instrument preparation scene the application provides a step-by-step instruction with a panel to the operator.

D. Performance test

The performance of the application should be analyzed; therefore, the error rate should be compared between the two assistance types. The paper-based checklist is compared against the AR application. To evaluate the impact on the different parts of the application, the errors should be differentiated by the method creation, batch creation, and instrument preparation. Through this, we can see the impact on the different task types; this was also suggested in [20]. Threw the industrial development environment; only dissolution-runs can be performed in the actual workload. Scientists are not available for additional tests and material and samples are cost-intensive. In the testing time also an internship will be in the development center.

III. Results

A. Evaluation of the use case

As mentioned in the previous part, we evaluated different tasks in the development lab and wanted to identify the most suitable use case.

Therefore we evaluated four tasks, manual dissolution, fully automated dissolution, HPLC, and Karl Fisher by their complexity, frequency, and how physical they are or if they are more computer-assisted or physical, and how novel they are in the department.

The fully automated dissolution shows the best use case since it is complex. Manual tasks are needed to assemble the instrument besides software tasks, and it was just introduced in the development department. Another factor is that the system is not frequently used; therefore, the user needs more support to ensure a stable and repetitive process. The system was always used by two users together with a checklist to improve the error rate.

Through this evaluation, we decided on the use case of the automated dissolution, which is evaluated in the following section in detail with the help of the evaluation framework for Immersive Analytics, see 3.

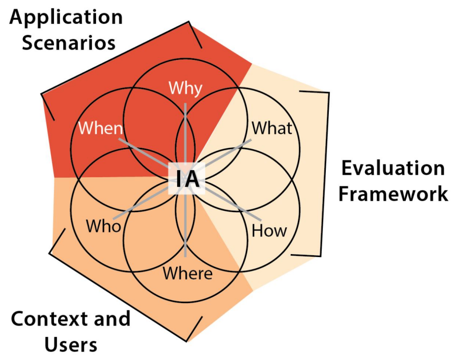

Fig. 3. Overview of the "User Scenarios and Evaluation." grand challenges. These challenges collectively consider how users and applications shape assessment in Immersive Analytics (IA) systems. [16]

1) Application Scenario - When and Why: To analyze the behavior of formulations, FDFs are dissolved in different media with different instrument parameters to determine the release of APIs over time. Dissolutions simulate different gastrointestinal situations like the full or empty stomach, and we can predict API blood profiles or maximal concentration for bioequivalence studies. Some methods are for quality assurance and batch releases of FDFs that are designed by the research and development (R&D) team and afterward transferred to the quality control group. Depending on the project, these dissolution runs have to be performed in-house. The AMD shows its benefit when multiple runs with the same media and the FDF are solid. Because of this, the instrument is not used frequently by every operator at the moment. Additionally, this system is relatively new to the user, and there is the need to extend knowledge, how to use this system efficiently in the R&D field. Why the system is so beneficial for large batches of dissolution is, that it can run multiple runs without a user's need to clean and prepare media for each run.

B. Context and Users - Who and Where

With this application, we want to support lab technicians and scientists with AR in the field of dissolution testing in a R&D environment. Besides working in the lab, this researcher is working on paper research, finding new analytic methods, designing laboratory tasks, and reporting them to the management. To analyze FDFs there are many different analytical procedures, that are described in SOP's and they need to be adapted to different FDF and active pharmaceutical ingredients (API).

1) Evaluation Framework- How and What: We decided to design an initial application that should support the users in all fields needed, from assembly the instrument to set up the system. For instruments, preparation holograms should help to find parts of the system. Tooltips and 3D models of the instrument should be used, therefore. Panels with text and images should also give the user advice. For the software part, the user can be assisted by a panel with descriptions and screenshots with highlighted areas. In the best case also the places where the user has to click should be highlighted on the desktop. To test the improvement from traditional usage with checklists in comparison with AR guidance the cancellation rate and the number of restarted dissolution runs should be evaluated.

2) Overall evaluation result: Through this evaluation, different critical needs for the user emerged. The user needs to be assisted by the creation of different dissolution methods in the software. The software consists of a graphical user interface (UI) and multiple menus for different settings. Besides that, the user should be guided through the creation of batches. By batches, multiple different dissolution-runs can be performed in sequence automatically by the dissolution apparatus. To address this also software guidance by HoloLens is needed. Before analysis, the dissolution system needs to be prepared with new filters, media, standards, sample vials, and samples. For better assistance, a modality of target recognition should be used to place objects in the environment. Objects can visualize assembly processes for improved support.

C. Software

1) Instrument preparation:

a) Target recognition: The first design iteration tried to detect four objects, dissolution bath, sampler, photometer, and multi-dosage unit in the instrument preparation. Therefore the user needed to register each part separately. Detection worked well with the multi-dosage unit as well as the photometer. This modality worked best for the multi-dosage unit. This unit is standing free on the table and has the best visibility. Besides that, it has just tiny transparent parts. For the photometer, the registration took more time. The user needed to walk around and look from different angles until it was registered to see figure 4. Mainly a wall reduced the visible parts of the object.

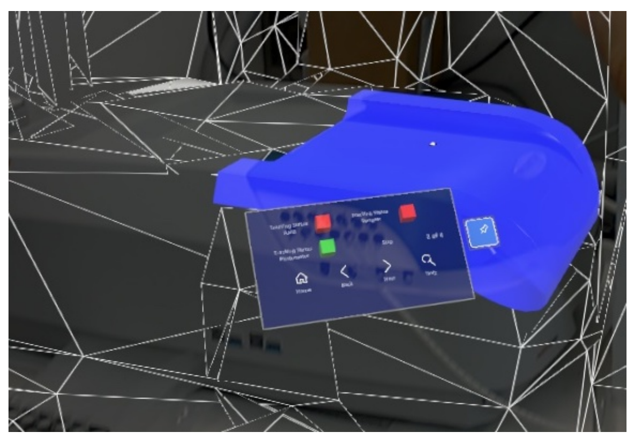

Fig. 4. Augmentation of the photometers flap that needs to be opened, the white lines shows the spatial map that is recognized by the HoloLens.

In fig. 4 the augmented flap of the photometer shows a small misalignment with the real flap of the photometer. This can occurred threw the complexity of the shape and the new creation of the 3D files. Detection for the sampler and dissolution bath did not work at all. These two parts have in common that they have large transparent areas. The water bath of the dissolution and the sampling room of the sampler is entirely transparent. Besides that, the sampler had the sample trays that can be mounted or not, which changes the appearances of the model. This can also lead that the Vuforia Engine wasn't able to detect the object.

Using the image tracking with static room calibration, just the image needed to be recognized to get the position of all dissolution parts. HoloLens 1 identified the image from a 2 m distance immediately and after adjusting the position and rotation of the objects it was precisely aligned for the application, see figure 7. Deviations were less than one centimeter.

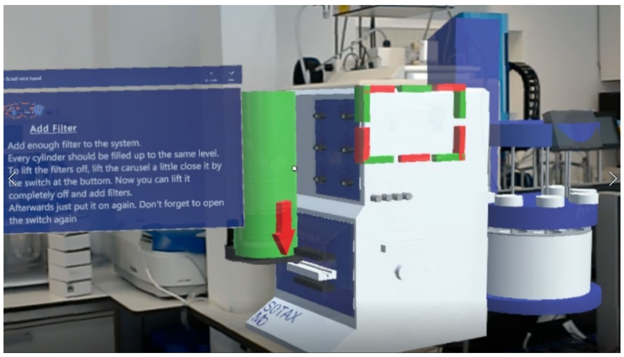

Fig. 5. HoloLens recognized the image, and the muti dosage unit was precisely overlapping with the real one. The position of the target image was framed by green and red rectangles. For guiding the user to the filters, a green cylinder covered the filters in this step. An arrow shows the switch to put off the filter stack.

By using extended tracking the holograms were still augmented when the image was out of FOV. This was needed that the user can go to the sampler and photometer where the target is out of the FOV, still the augmentations were very precise. Additionally, with the room calibration, tooltips can be placed on valves that are in the environment. The header turned with the position of the user and was well readable, figure 6.

Fig. 6. The tooltip anchored to the wastewater valve, that needs to be switched in this step. The panel contains additional information on when and how the valve should be switched.

The downside of these tooltips is that they do not organize automatically in 3D space. When multiple tooltips are used, they can overlay in 3D space and are no more visible and readable.

b) User interface: The UI for both solutions worked well; all steps can be opened and closed with the buttons. In addition, the UI showed the current step on the top of the near interface menu. The panel also worked well; manual position and scaling as well as follow me worked. The text was also good readable. For the model target recognition, the targets switched green when recognized. For the image target also a logo showed up when the application detected the image.

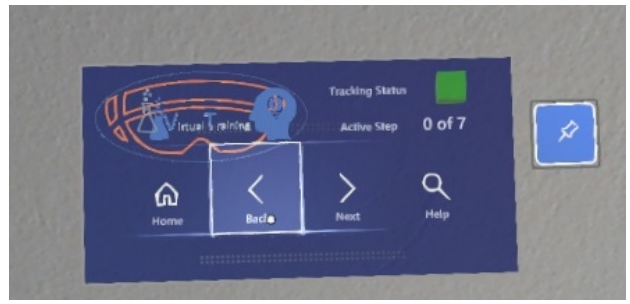

Fig. 7. Near interface panel with the registered image. Users can change the steps with the two buttons in the middle. The help button opens the panel with information, a home button switches to the start scene.

2) Software Instruction with AR: Another essential part of this thesis was to test if it would be possible to assist people working on the PC with augmented reality. Therefore, the system assists personas by showing them on panel screenshots what they should do, and additional static content gets direct help on the PC screen. For example, it was possible to show circles and squares as an overlay of the content for a fixed display. However, through the graphical UI for the method creation that can be zoomed and move, this option is unsuitable. As a result, graphics are shown in the wrong place. The UI itself worked well, steps can be switched, and by recognition of the image target, UI showed the logo.

D. Performance Test

The AR system was used for three weeks for 66 dissolution-runs and compared to 232 runs assisted by a checklist. The dissolutions were performed by four people. One tester, an internship, started just one run with the AR system. All persons had already training on the system from an expert, besides the internship. The user designed new methods and started batches with the assistance of AR and a checklist. Mainly malfunctions occurred through the creation of new methods, with both systems at a similar level, 2,9% for AR vs 3,3% for the checklist, see figure 8. A total error rate of 2,9% with AR and 7,9% with a checklist occurred. By the AR application, only malfunctions occurred by method creation. The error rate for method creation indicates that this is the most complex part of the whole application. The error rate was analyzed by ANOVA that shows no significant improvement for a p level of 0,05.

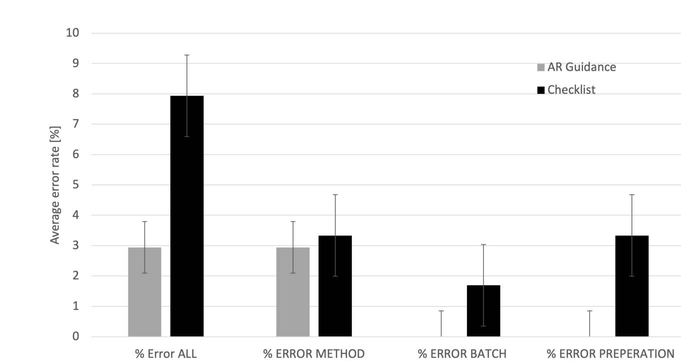

Fig. 8. After introduced AR for three weeks, tested by four person, the average error rate reduced from 7,9 % to 2,9 %. The error rate for the method creation stayed nearly the same. The highest impact had on the AR application was on the batch creation and the instrument preparation. All parts analyzed by an ANOVA (p¡0,05) showed still no statistical impact. Also, a bigger group of testers would be important.

People who used the checklist worked in pairs, while users with the AR system worked alone; an exception was the internship.

IV. Discussion

A. Can AR improve laboratory work in the pharmaceutical lab?

The main benefit of this application is that people without any knowledge of the system can learn how to assemble parts and configure the system. The system users need to know what parameters they need, and the application guides them through creating a new method and showing them where to add or change parameters.

Physical work augmented by an HMD can benefit most, though less needed time to find parts and attachments and fewer errors for inexperienced operators. The reduction of the error rate hasn't been significant in this study. Reasons could be that mainly experienced users made the tests. Besides them, an apprentice started a dissolution test that seen the system just once before and had no practical experience with it. She was able to perform a dissolution run without any error. This example shows that for less experienced persons, AR can have a higher impact due to less experience. Still, other studies also showed no significant impact for specific tasks due to lack of complexity [21], [22]. In this experiment, we tested that if AR can improve the error rate, this may be the wrong ratio in the pharmaceutical industry. In this environment, training and the use of SOPs minimized errors.

It would be better to measure the time improvement through the system or the reduction of the physical pressure through the system like in [23], [24]. Also, we have to consider that the test has been done initially by two persons with a checklist. With the AR system, just one person was preparing and using the instrument. Therefore, the reduction of needed persons assumes that HoloLens reduced the mental pressure.

To receive the full potential of an AR application also the user should be willing to use the system. Unfortunately, in industry, people mainly work on their tasks and do not have additional time to test new approaches.

Willingness to use the system can also be influenced by the social impact of the system. For example, multiple-sensor objective cameras are pointing to the world; people feel observed and uncomfortable. Pointing and making gestures in ”nowhere” looks for many people unnatural. To use the provided help, they also need to learn gestures and use them accordingly to work correctly. Without the right learned gestures, the experience with the HoloLens 1 lacks comfort. These gestures were optimized in the HoloLens 2, that all fingers are recognized, and the motions are more natural. Buttons can be clicked directly and don't need to be pointed with the cursor and confirmed by a gesture. HoloLens 2 will make the operation more comfortable for new persons into the field without any training.

On the other hand, the augmentation should be fast, and objects should be showing up in the right location without the need to look at an object for multiple seconds. Therefore one of the main findings was using the suitable target types for assistance in the lab. While using the application, it became clear that multiple object recognition is not practicable. However, because the instrument is static, it would be acceptable to recognize one object or target to reference the rest. Therefore, image recognition with static room calibration worked well; apparent area targeting would be the best solution for this stationary equipment. With area targets, objects can be placed precisely, and the environment is recognized on its own. It would be interesting how good this works with labs, where new instruments are set up, and old ones broke down. Beneficial would be that area targets can capture the whole floor, and the application can guide people through the rooms to different analytical systems.

Besides stationary equipment, mobile equipment can be recognized by a combined solution of target and model targets or feature-based targets would be the best solution. Fixed instruments are augmented throughout the time, while mobile equipment can be scanned and augmented just when needed. Similar to other studies where combinations of different target types are used to enhance precision and user experience. Instead of using 3D CAD files to teach the model, also LIDAR scans of objects would be a possibility to use model targets.

Guidance through software with AR can also be beneficial, but other techniques can probably be more convenient without an HMD. Steps can be augmented directly on the user desktop as an overlay on the screen. Through that they wouldn't suffer from heavy HMD, especially more minor persons [8].

Besides that, the usage of another target type for software instructions would be more efficient because this scenario works just with the used desktop and format. Feature-based or multiple image targets would make the system more flexible for the user. The application must be scaled full screen and can't be adjusted due to using a single image target as a reference. Still, it's not clear if multi image targets would be reliable with an HMD due to the distance and scale of the targets.

Tooltips were also used and showed the user the position of the instrument parts. When using multiple tooltips from the Microsoft toolbox in a small area, the downside is that they can overlap and text from some tooltips is not readable.

A pane-based occlusion management approach can handle this issue, to place labels with distance to increase readability [25].

Users also would benefit from hands-free user interaction to switch tasks. Especially for two-handed actions, this would be beneficial like in [14] application. Users do not need to shift their focus on the input and manipulate holograms with hands. Besides that, another improvement would be to make instructions more interactive in the form of videos, simulated holograms, or read-out instructions. Gamification of instructions through points, ranking, and personalizing the application can motivate and engage people [26]. Therefore different modes would be helpful, for instance, a competitive and a non-competitive way, where people can see how fast they are. Then, when users use the system more frequently, they can get batches from trainees to an expert to see their knowledge status, and at a certain point, they will not need the guidance anymore. The first step in this direction was made using the current phase and holograms of equipment; still, there is significant potential in this field.

People will use HMD to bring them a specific improvement, like a more stable process, reduction times, or training for inexperienced or new users. Therefore the system must be intuitive to use and no further training's needed. Unfortunately, when people used HoloLens initially, they need to learn gestures and calibrate the display because multiple users used the same device. This drawback is investigated and improved by Microsoft HoloLens 2, where through eye-tracking calibration isn't needed and gestures are more intuitive [3]. Also, another user claimed the small field of view from the HoloLens 1, through that holograms weren't fully visible. ´ Programming own applications specific for lab tasks can use target types that are preferred and aren't limited by the software. Game engines like Unity or Unreal are user-friendly platforms that use packages to implement tracking with a minimum knowledge of programming languages. Still, some programmings skills are needed to utilize them. [10]

To enable companies without the required programming skills, new approaches get on the market that helps to deal with this lack of experience, like Microsoft Guides or solutions from PTC where programming isn't needed at all [7].

B. Can AR reduce the documentation work in the lab?

Because HMD isn't allowed to pick data and process them nowadays, AR will not reduce the documentation work in the pharmaceutical industry lab. In other fields, the potential of AR for documentation is already evolving in the context of augmented documentation [27], [28].

It is more of an assisting tool to make experiments more reliable. Through this help, deviations are reduced. By this, the reports of deviations are reduced, but this is just a passive effect. Multi-platform solutions for documentation in the GxP environment are needed. Microsoft Guides, for instance, can report through the use of the AR instructions, lead times, time per task, and other functions. Still, there is no application there where AR can process raw data to a lab report. Therefore balances and equipment need to communicate together and store their data on a shared database, like internet of things do. Different platforms can then use data to create reports or use the data to visualize data in traditional and IA applications. Another exciting part will be the impact on the four-eyes principle. AR can assist and check the tasks by task recognition.

In the future, there will be start-ups or companies that design applications like this, specific for labs under GxP, but this needs a lot of effort. The pharmaceutical industry will use applications on the market and implement them to evolve and transform their essential business. AR will play a role in some terrains but more in the not regulated content until there are solutions.

V. Conclusion

AR in a laboratory field is a future technology to use. Especially for tasks that are not that frequent and complex, and there are other fields like tech transfer described in [8]. For the acceptance of the technology, the workflow has to be designed well, that there are no further malfunction and a decrease of incorrectly performed experiments.

For the augmentation of objects in 3D, suitable targets need to be used for unrestricted use. Object recognition has benefits, but it is not that fast and stable as marker-based recognition at the moment. Especially in a laboratory field where you have to handle multiple types of mainly stationary equipment, area targeting or image-based room calibration has a better workflow. Object recognition is also limited to not flexible and rigid bodies. Moreover, object detection gets inefficient when tools are opened and have moving parts. For better object detection, use of LIDAR scans would be a option. Still, detecting all the pieces on its own isn't that effective, especially when objects are stationary.

Obvious AR has not just the possibility to guide; it would also be interesting to help document experiments. From gudiance to capturing videos for tech transfer to the documentation of data or visualization. In this area, data security is critical; therefore, it would be essential to have a split network, one for storing data via wire and one for using data for AR, also possible via Wifi.

This approach needs a lot of effort to implement a database, provide compatible internet of things like balance, pH-meter, and other necessary instruments.

Having step-by-step instruction is a step in the right direction, but there is still potential for improvements. With AR, new operators can learn tasks more efficiently and faster, but the proper target registration is essential. With faster and more stable object detection, quality assurance and the four-eye principle AR can be an exciting field in the lab environment.

Lab operators will work with AR techniques in the future, but just for complex and hard-to-fulfill tasks or where it has a significant advantage over a regular SOP. For example, in a release laboratory or in plants where things happen frequently and are complex, HMD has a field when AR can automate documentation in the future. Parallel in development, there are plenty of fields of use from training to work. In this environment, changes happen faster, and because of this, applications must be more versatile and easy to adapt. Therefore solutions without programming skills for scientists and technicians would be sufficient.

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