Towards Analytical Laboratories 4.0: Leveraging Augmented Reality

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Abstract—**The pharmaceutical industry has been facing challenges which have driven it to find new ways of increasing productivity and optimizing processes. To this end, pharmaceuticals are implementing the paradigm of Industry 4.0 with the name of Pharma 4.0. This strategy includes the implementation of technologies that aim at automating processes but also at increasing the worker's job performance. One of this technologies is augmented reality (AR), it augments the vision of the worker with information relevant to the task at hand. This thesis proposes an augmented reality application that aims at facilitating the worker's job while following the procedures in the analytical laboratory of a pharmaceutical company. The application shows procedures in a step-by-step guide which can be consulted using smart glasses. Furthermore, in order to provide a hands-free solution, speech and gesture recognition were implemented successfully, providing a flexible way for the analysts to consult such procedures while performing the tasks. This thesis also presents a case study, following the technology acceptance model, in order to understand the value of such system in a pharmaceutical analytical laboratory. The results of the study show that such a technology can be very beneficial. The analysts reported that the tool was useful in their day to day lives. It was concluded that the application is a valuable addition to the laboratory, although many improvements can still be made.**

Index Terms—**Pharma 4.0; Analytical laboratory; Augmented reality; Hands-free navigation; Technology acceptance model**

I. INTRODUCTION

Recently industry has been implementing new technologies in order to accommodate the changes brought by Industry 4.0 (I4.0). Several of these technologies have allowed for highly autonomous manufacturing systems, providing a greater productivity capacity and reducing human errors. Pharmaceutical companies have also been adopting this new model, under the name of Pharma 4.0, with the objective of increasing productivity and reducing the time-to-market of new drugs to overcome the challenges that have been affecting the industry in the past years.

Although Industry 4.0 technologies aim at making processes autonomous, there are still tasks that are impractical, or even impossible, to complete without human intervention. Many of the tasks in the pharmaceutical laboratories fall into this category, where although the workers are assisted by the machine, they still play a crucial role in completing necessary tasks. It is for this reason that one of the 9 pillars of the new Industrial Revolution is augmented reality (AR) [1]. Industry 5.0 complements the existing I4.0, but changes the main focus from digitalization for increased flexibility and efficiency, to sustainability and human-centered technologies. It aims at an increased collaboration between humans and smart systems, making augmented reality a core technology of this new paradigm [2].

This work is the product of a partnership between Instituto Superior Técnico and Hovione Farmaciência, S.A.. Pharmaceutical companies, such as Hovione, have many areas were procedures need to be carefully followed. Information is accessed using different tools such as paper, computers or tablets; and different formats such as manuals, documents, flowcharts etc. In Hovione's analytical laboratory, to perform a certain task, the analysts must follow a set of instructions represented by a flowchart, which is consulted using a small computer that the analysts must carry around. Some tasks are performed in workbenches while others are performed standing, in a fume hood, or using a specific machine, where there is no space available to put down objects. The workers in the lab require both hands to perform the necessary tasks. The way that analysts are currently accessing the flowcharts has a set of disadvantages such as the attention switch, which is cognitively expensive, not being hands-free, which means that the analysts must stop their tasks to consult the procedures, and the cross-contamination risk. These disadvantages manifest the need for improvement of these processes. Augmented reality can substitute the current way the flowcharts are consulted and provide a more convenient, fast, productive and overall easy way of going about the procedures in the laboratory. Therefore, this thesis proposes an Augmented Reality system that will be used to transfer these flowcharts from the workbench to the analyst camp of vision in a step-by-step guided application running on smart glasses that can be navigated hands-free, eliminating the problems stated above. This work also presents an evaluation of said application in order to assess if this type of system helps the analysts in their tasks, improving their productivity and facilitating their work, and is therefore a valuable asset.

The work is divided as follows: **Section II** briefly introduces the Pharmaceutical Industry and Pharma 4.0 operating model, and describes the motivation, objective and contributions of this thesis. In **section III** the Augmented Reality technology is introduced. In **section IV** the development of the application is presented, detailing all its components and features. Also the smart glasses used are briefly described and compared with other solutions in the market. **Section VI** contains the description and results of the case study conducted to evaluate the users acceptance. Finally in **section VII** conclusions, achievements and future work are presented.

II. PHARMACEUTICAL INDUSTRY AND PHARMA 4.0

The pharmaceutical industry aims at discovering, developing, producing and marketing pharmaceutical drugs. Due to the nature of its product, the pharmaceutical industry is one of the most regulated industries today. Entities like the Food and Drug Administration (FDA), in the United States, European Medicines Agency (EMA), in Europe, and Infarmed, in Portugal, ensure that the drugs produced by these companies meet the necessary standards through the Good Manufacturing Practices (GMP) and Good Laboratory Practices (GLP) regulations. The pharmaceutical industry is thus driven by high standards of quality and safety in the research and manufacturing processes, in order to comply with the regulations, and ensure the health of both consumers and workers. The International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH) is an organization that brings together the pharmaceutical companies and regulatory authorities to promote public health by discussing scientific and technical aspects of pharmaceuticals, and developing guidelines and requirements for pharmaceutical product registration and thus achieving a greater harmonization between these entities.

Pharmaceutical companies have been changing in the past few years due to increased competitiveness in emerging markets, shortage of patent lives and drug pricing laws. The necessity to increase productivity and optimize processes has led to the adoption of new strategies, namely the adoption of Pharma 4.0. The International Society of Pharmaceutical Engineering (ISPE) describes Pharma 4.0 as an operating model that joins digitalization and ICH Q10 guidelines.

ICH Q10 is a quality guideline targeting the Pharmaceutical Quality System (PQS), applicable across the life cycle of the product, which complements the existing GMPs. It encourages the improvement of manufacturing processes by applying technical innovation, continual improvement policies, data monitoring and preventive action culture. Digitalization allows for a fully integrated value chain, where data can be continuously gathered in order to improve processes, help workers decision making, and have autonomous systems. The combinations of these two concepts creates a powerful strategy that pharmaceuticals can follow in order to gain a competitive advantage in the market.

A study containing a survey to pharmaceuticals revealed that the principal areas of focus of companies when implementing Industry 4.0 included optimizing processes, monitoring plant performance, ensuring regulatory compliance, and minimize downtime. It also stated that one of the top Industry 4.0 elements being used is Augmented Reality, which can be a valuable asset in tackling any of the focus areas mentioned [3]. AR brings a new type of human-machine interface that allows the workforce to have a better performance in the new smart factory, providing information, assistance and guidance in a flexible way.

III. AUGMENTED REALITY IN INDUSTRY

Augmented reality (AR) is an emerging technology that connects the physical and virtual worlds. It enables the user to easily access relevant information in real-time while still being aware of the real environment. Unlike Virtual Reality (VR), that fully replaces the real world with a virtual one, AR can be used in settings where the real environment is relevant, or when not seeing the surroundings can even be dangerous. AR uses an electronic device, such as a smartphone, or head-mounted device (HMD), to superimpose virtual objects on the users field of view (FOV). This way of collecting information is more complete than simply seeing the information on a screen or piece of paper, since it is shown in the real-world context that it is related to.

Although the concept has been around for some time, AR has only began to be more greatly implemented in the past few years, enabled by the leaps in miniaturization. The appearance of smartphones had a great impact in the technology since they allow for considerable computational power in anyone's pocket. The game *Pokemon Go* is a good example of the mainstreaming of AR due to the usage of smartphones, it was one of the greatest hits of AR, being one of the first applications to became known worldwide. The advances in technology also allowed for the recent commercialization of different head-mounted displays that further allow for the implementation of the technology in industry.

A. Applications of AR in Industry

Augmented Reality is currently used for different industry applications, the most common ones being maintenance, assembly and training [4]. Since AR is still a growing technology, most implementations in literature about the topic have been carried out in laboratory settings [5]. In this section some of these applications are described as well as their conclusions.

Maintenance is a common field in AR applications since it can greatly benefit from the technology. Remote maintenance is the performance of maintenance tasks when the expert is not present on-site. Using AR, the expert can guide the operator in the procedure. Mourtzis et al. [6] proposed a remote maintenance system featuring AR and video conference, the expert would follow the operator in the procedure through a computer, the operator would use an HMD or mobile device to stream his view and get instructions. The work concluded that this type of maintenance approach would lead to reduction of costs and decrease in the machines downtime, increasing productivity.

Assembly/disassembly tasks can benefit greatly from AR, this tasks usually involve procedures that can be converted into step-by-step guides. Hou et al. conducted a study where an AR system was tested to guide workers in a piping assembly, results showed that the completion time of the task were reduced compared to conventional methods, a decrease in the number of errors and the cognitive workload were also observed [7]. Mura [8] developed an AR guide for the support of panel alignment in car body assembly. By comparing the AR system with the conventional method, it was noted that the assembly task when performed with the AR tool was completed almost four times faster.

Companies have to spend time and resources providing training sessions for their workers. AR has the capability of making this process more efficient. Training AR applications in industry are often related to maintenance and/or assembly tasks. Macchiarella [9] conducted a study where four types of training methods, applied to a maintenance task, were compared: a video-based presentation, a print-based presentation, an augmented reality presentation and an interactive augmented reality presentation. It concluded that the augmented reality based instructions lead to an increased long term memory retention.

Augmented reality applications in the pharmaceutical industry are very scarce in literature, one application was found presented by Forrest et al. [10], which proposed a remote assistance system using Microsoft HoloLens headset similar to the remote maintenance described at the beginning of this section. The authors propose to use the same type of video conference to transfer experimental methods across multiple pharmaceutical laboratories, eliminating the sharing of this type of information through written protocols that many times lead to error and resulted in inefficient information transferring. The solution could reduce the travel time of the scientists between laboratories and associated costs, and reduce the overall drug development time. The lack of research regarding augmented reality in the pharmaceutical industry shows a gap in literature, even more having into account that pharmaceuticals have an unique way of operating.

B. *Evaluation of Augmented Reality Acceptance*

The Technology Acceptance Model (TAM) has been the most used model for the evaluation of technology acceptance since it was first introduced by Fred Davis in the 1980s. Davis based this model in two user perceptions, usefulness and ease of use, arguing that these two perceptions were the ones that mostly correlated with the acceptance of a new technology. He stated that if people believe the system will help them perform their job better, there is a higher chance of using the system (perceived usefulness). Also, even if the system is useful, it cannot be so hard to use that the effort of using the system outweighs its benefits (perceived ease of use) [11]. The original TAM aimed at evaluating how this two variables affect attitude toward using and, consequentially, behavioral intention to use the technology. The model is evaluated by using the correlation between the variables scores, which are collected by using a questionnaire filled by people that experimented with the technology. Since F. Davis publication, several studies have used this method to predict user acceptance and others have extended the model to include other variables.

TAM has been used to evaluate the acceptance of augmented and virtual reality technologies. A variable that is often included in these models is perceived enjoyment, which is defined as “the extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system use” [12]. Perceived enjoyment can be correlated with perceived ease of use and with intention to use [13]. A second variable used with augmented and virtual reality technologies is personal innovativeness (also sometimes called perceived innovativeness). This variable was proposed in 1998 by Agarwal Ritu and Jayesh Prasad [14]. They defined is as “the willingness of an individual to try out any new information technologies”. The authors noted that a high perceived innovativeness led to a more likely adoption behavior. Other studies [15], [16] have also concluded that perceived innovativeness has a positive effect in perceived usefulness and perceived ease of use. Another evaluated aspect of virtual environments is cybersickness. Cybersickness is the negative side effect that might afflict a person when exposed to a virtual environment. It has similar effects as motion sickness, such as nausea, headaches and dizziness. Cybersickness symptoms can be more or less severe depending on the rendering modes, visual display and application design, they also affect people differently. They can impact the users comfort and, more importantly, their health, having the possibility of inflicting injury or decreased capacity [17]. Being a negative outcome of the exposure to virtual environments, this side effect might influence the acceptance of users to augmented reality systems, therefore this variable is sometimes included in the TAM to assess how it influences user acceptance. The Simulator Sickness Questionnaire (SSQ) [18] is often used to evaluate the symptoms due to simulation exposure.

IV. AUGMENTED REALITY APPLICATION FOR THE ANALYTICAL LABORATORY

The objective of the Augmented Reality application is to guide the analyst through the laboratory procedures, in an natural and easy manner, concentrating different information in one place, and allowing all this to happen hands-free, in order to increase the workers productivity and reduce cognitive load.

Hovione has an internal knowledge management tool - Excellent Development and Manufacturing (EDaM) - designed to be a shared knowledge center where R&D scientists can create workflows for members to consult. In the analytical laboratory it is common for the analysts to consult these workflows to follow procedures. This tool is web-based, which makes it real-time updated. It is directly from this knowledge center that the information used in the application is retrieved.

The application allows the user to follow the procedures in a step-by-step guide, consult different types of information and supports hands-free navigation. The information flow between the different software components is presented in figure 1.

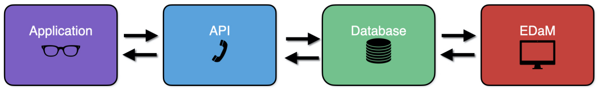

Fig. 1: Information flow between the different software components

A. *Augmented Reality Device*

The Augmented Reality device used was the Moverio BT-300 smart glasses, which were the ones chosen by Hovione for the development of this project. The Moverio BT-300 smart glasses include an optical see-through display with a field of view (FOV) of approximately 23 [19]. Fraga-Lamas states that the field of view should not be lower than 30 in order to have a good user experience [20], so one can note that the FOV of the Moverio BT-300 is somewhat low, however, for the purpose of this thesis, it is sufficient.

The user navigates the interface in the Moverio Epson BT-300 smart glasses by using a controller. The controller navigation is similar to that of an Android smartphone, making it easy and natural to use.

Moverio BT-300 are currently the lightest binocular, see-through smart glasses on the market. Light-weight is a valuable characteristic in smart glasses, since these are to be worn for long periods of time [20]. Heavy glasses are uncomfortable and can cause injuries to the worker. The battery life of the Moverio BT-300 lasts up to 6 hours, which is above average compared to other smart glasses ($\simeq$ 4 hours) [20].

B. Application Programming Interface

An Application Programming Interface (API) was built in order to establish the communications between the client (application) and the company's database. The language used was Python. This API was also used to make some other operations that will be detailed bellow. Figure 2 represents the information flow between the client, API, and database, as well as the operations performed by the API.

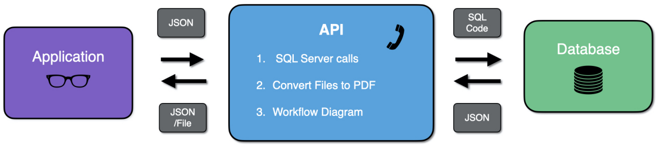

Fig. 2: API

1. SQL Server Calls: The main purpose of the API is to retrieve information related to the workflows using SQL server calls. First a list of workflow names and the corresponding knowledge areas (KA) are retrieved. After the user selects a certain workflow from this list, the workflow itself is fetched from the database, as well as information regarding who made it and/or last modified it. The list of resources related to a certain knowledge area are retrieved when the KA is settled and the resource itself is retrieved when chosen. Depending on the type, the resource may need to be converted inside the API, as explained bellow.

2. Convert Files to PDF: Since it is not possible to display a Word or Power-Point file inside an Android application, this type of files had to be converted to PDF format, which can be embedded in the application using a PDFView.

3. Workflow Diagram: The diagram of the workflow is obtained by using the *Python* library *pyvis* When the user selects the option to see the diagram, the JSON containing the current workflow is sent from the application to the API and is then transformed into a *pyvis* graph. This diagram is written to an HTML file that is sent to the application and displayed in a WebView.

C. Application Workflows

The application transforms the workflows made with EDaM into step-by step guides in order for the analyst to follow them more easily. In the company's database, the workflows information is stored in JSONs, that are built, edited and read by the EDaM tool. These JSONs are passed to the application by a call to the API specifying which workflow to retrieve based on the user's choice. The information is retrieved from the JSON and is stored in objects. Some JSONs containing the workflows information were gathered to understand which types of nodes and links were present and which information was relevant. Also from these JSONs the linking logic was retrieved and mimicked inside the application.

D. Auxiliary features

Throughout the application, in certain activities, the user can assess other features using the options menu.

Resources: The resources feature allows the user to consult documents or multimedia related to the task at hand. While inside a workflow, the user can choose this option to see a list of all the resources available and choose one from the list.

Created by: This feature allows the user to consult who created and/or last modified the workflow that is currently being consulted. By using this feature the user sees the name of the colleague and his email, being able to contact him in case of needing assistance.

Diagram: The diagram feature allows the user to see the full diagram of the workflow. The diagram is made inside the API, returned to the application in the form of HTML and displayed in a *WebView*.

To the Beginning: This last feature allows the user to go directly to the initial menu.

V. ALTERNATIVE WAYS OF NAVIGATING THE APPLICATION

While performing different tasks in the laboratory it was important that the user could use both hands, not only for convenience, but also for safety measures. In order to make the system hands-free, two different possibilities of navigation were implemented: speech recognition and gesture recognition. The implementation and evaluation of each of these solutions is detailed in the sections bellow.

A. Navigation by Speech Recognition

For the implementation of the speech recognition feature the Vosk toolkit was used. Vosk is a free, offline toolkit compatible and easily integrated with Android. Vosk library was integrated in the Android Studio Project and a service inside the application was made to implement the speech recognition feature. Each time the users speaks, the service sends the output to the current activity, which compares it to its list of commands using Levenshtein distance (LD). The Levenshtein distance measures the difference between two strings. It is the minimum number of single-character edits (insertion, deletion or substitution) required to change one string into the other [21]. This distance was chosen since it is the most commonly used in similar situations.

In the application, the Levenshtein distance is calculated between the Vosk model output and each command, if this distance is zero, the function automatically returns the respective command to be executed, otherwise, an array of distances is created. From this array the smaller value is found. If there are two equally smaller values, the result is inconclusive. If there is only one, but the value of the distance is greater than the maximum of the two lengths of the words compared, the result is also inconclusive. In these two cases the user is asked to speak again. Otherwise the function returns the command that scored the minimum distance.

A test was created to evaluate the speech service in the context of the application. The test consisted in speaking three different sequences of thirteen commands and checking how the model recognized them. The test was completed by two people. The tested commands are the ones used in the application's navigation, although some similar commands were left out (e.g. "scroll down", for being similar to "scroll up"). After evaluating the 78 predictions, it was observed that the speech model failed to correctly predict 23 (the spoken word was not exactly the same as the model output word), but applying the LD, only 8 would not have been recognized by the application which demonstrates the importance of using the Levenshtein distance strategy. From these results we can say that the Speech Recognition service is detecting words with a 90% accuracy, although it is important to notice that these results were acquired in a different environment than the laboratory, with no background noise, and that the words were spoken by only two people. Noise, different accents and other aspects may affect the accuracy. There was only one case were the command was misinterpreted by a different command, the word spoken was "voice commands" and the recognized command was "show documents".

Besides the commands, the application also has to recognize the names of the knowledge areas and of the workflows, which can be variable over time. In order to prevent misinterpretations, especially for workflows whose name is an acronym, these lists were numbered, therefore the user can simple say "number x", x being the number corresponding to the wanted item on the list, instead of saying the text of said item.

The speech service starts running when the application is started, and immediately a window appears which informs the user that the service was started, shows the basic commands, and has an option to cancel if the user does not want to use this feature. At any time the user can mute/unmute the service by clicking the volume buttons on the controller. This allows for the user to speak to a colleague while using the application and eliminates the risk of unwanted commands being recognized. To further prevent the app from taking unwanted commands, a keyword was implemented as well. When starting the step-by-step guide, the user must say the word "glasses" before any command in order for the command to be recognized.

B. Navigation by Gesture Recognition

The gesture recognition feature allows users to use hand gestures to navigate the application. This feature was added in order to further improve the hands-free component. Unlike the speech recognition, the gesture recognition feature was implemented to only be used with the step-by-step guide of the workflow.

The workflow step-by-step guide is based on 3 types of interactions: go back to the previous task, go to the next task or choose from a set of options that can fall under two categories: the options from the workflow itself or the four auxiliary features. Six gestures were thought of to navigate, which are represented in figure 3[1].

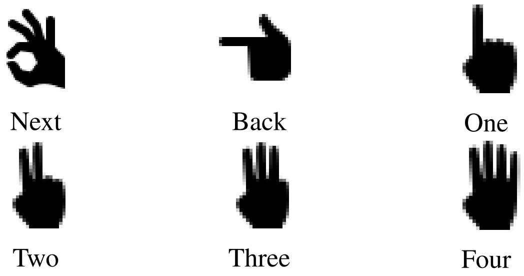
Next Back One
Two Three Four

Fig. 3: Icons representing the gestures used to navigate the application

To implement the gesture recognition feature some machine learning models were trained to classify the gestures, using the TensorFlow Python library. The deployment of models trained with TensorFlow to mobile application is straightforward, using TensorFlow Lite. A sample project that uses TensorFlow Lite with Android is available, which was later used to test the gesture recognition feature and to integrate it in the application.

Object detection models were trained to detect the gestures. The TensorFlow 2 Object Detection API was used, running on a Google Colaboratory notebook with access to a GPU. This API gives access to a list of models (model zoo) pre-trained on the COCO 2017 Dataset, which one can use for transfer learning [22]. Out of these models, only the SSD ones are eligible to use with TensorFlow Lite, since this type of detector has significantly lower computational power needs, compared to other detectors, and therefore can be used in devices such as smartphones and, in this case, the Moverio smart glasses.

Dataset Description

The dataset used for training is composed of images with hands making the different gestures as well as some images with hands that do not represent any gesture in particular ("None" of figure 4). Examples of the images used are presented in fig 4.


Next Back One

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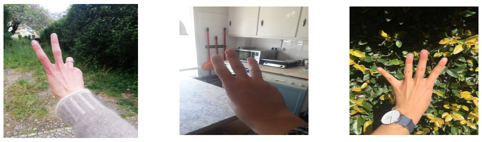
[1] Icons retrieved from https://icons8.com/



Two Three Four

None

Fig. 4: Examples of images in the dataset

Two different datasets were used in different models. One model was trained with only the six gestures images, other two models used an additional set of “None” images. The datasets were divided into training and testing sets. The testing set is constituted by 2 images of each of the gestures (12 for model without “None”, 14 for models with “None”). The training set is constituted by the remaining images (153 for model without “None”, 192 for models with “None”).

Training

Three different models were trained and tested in order to find the one that best suited the problem. All of the models use the SSD Mobilenet v2 FPNLite architecture [23], no changes where made to the default architecture provided by TensorFlow, other than the number of classes, the number of training steps and the batch size (that was set to 4).

Table I shows the different models trained with the respective input sizes of the image, number of labels (6 for the one without the “None” label, 7 for the ones with the “None” label), number of training steps and Mean Average Precision (mAP).

Id	**Input size**	**No of labels**	**No of Training Steps**	**mAP** (IoU=0.5:0.95)
1	320x320	6	13000	0.846
2	320x320	7	15000	0.704
3	640x640	7	9000	0.708

TABLE I: Tested models metrics

Tables II, III and IV show the confusion matrix obtained using the testing set for models 1, 2 and 3, respectively. Model 1 confusion matrix shows that all the predictions are correct, it is also the model with the higher mAP. The reason for this may be that with the addition of the 7th class, the model became “confused”, since this class consists of many different gestures.

		Ground Truth						
		Next	**Back**	**One**	**Two**	**Three**	**Four**	**Nothing**
Prediction	**Next**	2	0	0	0	0	0	0
	Back	0	2	0	0	0	0	0
	One	0	0	2	0	0	0	0
	Two	0	0	0	2	0	0	0
	Three	0	0	0	0	2	0	0
	Four	0	0	0	0	0	2	0
	Nothing	0	0	0	0	0	0	0

TABLE II: Confusion matrix model 1

		Ground Truth							
		Next	**Back**	**One**	**Two**	**Three**	**Four**	**None**	**Nothing**
Prediction	**Next**	2	0	0	0	0	0	0	0
	Back	0	2	0	0	0	0	0	0
	One	0	0	2	0	0	0	0	0
	Two	0	0	0	2	0	0	0	0
	Three	0	0	0	0	2	0	0	1
	Four	0	0	0	0	0	2	0	1
	None	0	0	0	0	0	0	2	0
	Nothing	0	0	0	0	0	0	0	0

TABLE III: Confusion matrix model 2

		Ground Truth							
		Next	**Back**	**One**	**Two**	**Three**	**Four**	**None**	**Nothing**
Prediction	**Next**	2	0	0	0	0	0	0	0
	Back	0	2	0	0	0	0	0	0
	One	0	0	2	0	0	0	0	0
	Two	0	0	0	2	0	0	0	0
	Three	0	0	0	0	1	0	0	1
	Four	0	0	0	0	1	2	0	0
	None	0	0	0	0	0	0	2	0
	Nothing	0	0	0	0	0	0	0	0

TABLE IV: Confusion matrix model 3

Looking at the confusion matrices of models 2 and 3, model 2 shows some false positives, but it detected all the gestures. Model 3 failed to detect correctly one image, it also shows some wrong detections.

The number of training steps of model 3 is considerably lower than the other two models, this is due to the fact that this model was soon discarded once it was tested in the android application due to its high latency while making detections in real-time. Models 2 and 3 have almost the same mAP, but model 2 had more training steps, this is because the larger image input size provides the model with better accuracy, since it can gather more features from the image, this is why this architecture was tested, but by assessing its decrease in speed, this and other more computational heavy models were discarded for this task.

After training, the models were deployed to the android application provided by TensorFlow in order to evaluate them in real-time, model 3 was discarded at this phase and it was not further tested. These tests were not made using the smart glasses, since they were unavailable[2], but using a different android device with similar specifications in terms of processing power.

The test consisted of making three sequences of nine gestures to be detected by the android application in real-time. The nine gestures consisted of the six gestures that trigger the commands (from figure 3) and three additional random gestures (five, closed hand and holding a pen) to represent the "None" class, the objective of this classes was to be detected as "None" (only by model 2) or to not trigger any detection.

The results consisted of gathering each prediction and its level of confidence. A first test was made with an initial confidence threshold of 90%. Analyzing these results it was noticed that the threshold could be increased to 98% since this would maximize the correct predictions while minimizing wrong predictions. A second test was performed with the 98% threshold.

From the results of both tests, table V was then constructed in order to compare the four models. It shows the percentage of True Positives and False Positives detected by each model. With these results we can see that the threshold did improve the result of model 2 by 4%, but the results for model 1 worsened.

	90		98	
	TP%	FP%	TP%	FP%
Model 1	78	22	75	23
Model 2	84	16	88	12

TABLE V: Comparison True Positives and False Positives percentage for each model and threshold value

Evaluating all these results the natural choice would be model 2 with a 98% threshold, which performed 10% better than model 1. Nevertheless, it is important to notice that many aspects might have changed these results:

- The results were not performed with the Smart Glasses, but with a different device
- The gestures that represent the "None" class were made explicitly to the camera, which would not happen in the real environment
- Light and background variations - the tests were not performed in the environment where the system will be used

The next evaluation step for these models would be to test them in real life conditions, i.e. in the laboratory, using the smart glasses, ideally following a procedure.

Android Implementation

A second application was built to run the camera and detections in the background. This application was built on top of the TensorFlow Lite example for android that was mentioned in the paragraph "Machine Learning for Gesture Recognition". Some changes were made in order to not show the camera preview while running the app and run the camera as a service that can be started from the other application and send it the results.

VI. USER ACCEPTANCE OF AUGMENTED REALITY SYSTEM IN THE ANALYTICAL LABORATORY

A. Technology Acceptance Model

To evaluate the user acceptance of the augmented reality system an extended technology acceptance model was used. To the original model that includes the variables **perceived usefulness** and **perceived ease of use**, were added other variables that were found to be relevant in the the acceptance of similar systems. These variables were: **perceived enjoyment**, **personal innovativeness** and **cybersickness**. The cybersickness component was evaluated using a version of the Simulation Sickness Questionnaire. A sixth variable was also included since it was noted that the augmented reality wearables were many times regarded as not comfortable, this variable was called **ergonomics** and is related to the comfort and consequent effectiveness of using a wearable device. Masood and Egger mention ergonomics as one of the most reported challenges for the implementation of AR [24]. The AR wearable devices have not yet reached maturity and need further technological development to be able to have both capable hardware, and be comfortable to wear, not injuring the users or affect their job. This variable was introduced in the model to understand the users perception of ergonomics of the Moverio Epson smart glasses and how it affects the intention to use the system.

All the variables definitions and the questions that were included in the questionnaire to measure each variable will be described bellow.

B. Case Study Procedure and Questionnaires

In order to assess the acceptance of the analyst towards the developed application a case study was conducted. The case study was made in Hovione's R&D analytical laboratory and had the participation of 4 analysts. Due to the pandemic situation, the facilities had restricted access and the laboratories were operating with less people, which made it hard to get more analysts to participate.

Procedure

The case study was divided into the following steps:

1) It was explained to the analyst the purpose of the experiment, how to use the glasses, and the basics of the application usage
2) The analyst filled a pre-questionnaire
3) The analyst used the glasses and the application to perform tasks in the laboratory
4) The analyst filled a post-questionnaire

During testing time, the analysts were free to choose the workflow performed and what features to use. Each analyst may have used different workflows and features. Each analyst was also free to test the application more than once, the number of times each analyst performed a task using the system were not recorded. The tested application integrated the speech recognition navigation, but not the gesture recognition one, since this feature was developed while the tests were ongoing.

Questions Included in the Pre-questionnaire

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[2] The smart glasses were being used in the laboratory in order to gather the user's feedback

In the pre-questionnaire the participants were asked about the following topics:

- age group
- education level
- field of study
- time working at the current position
- previous experience with augmented reality
- excitement level regarding the experiment
- expectation level regarding augmented reality in the laboratory

These topics were included to provide a general idea of the participants background and expectation for the experiment.

Questions, Variables and Statements Included in the Post-questionnaire

The post-questionnaire started by asking what type of workflows and what features were used, some questions related to the speech recognition were also asked. The following questions were constructed in a 7-point likert-type scale, except the SSQ, whose symptoms are rated between none, mild, moderate, severe and very severe.

Bellow are the statements that were included in the questionnaire to evaluate each of the variables and the included symptoms from the SSQ.

Perceived Usefulness

- Using the system improves my job performance
- The system allows me to accomplish tasks more quickly
- The system increases my productivity
- The system is useful in my job.

Perceived Ease of use

- The system is easy to learn.
- It is easy to get the system to do what I want.
- The system is clear and understandable.
- I find the system easy to use.

Personal Innovativeness

- If I heard about an information technology, I would look for ways to experiment with it.
- Among my peers, I am usually the first to try out new technologies.
- In general, I am excited to try out new technologies.
- I like to experiment with new technologies.

Perceived enjoyment

- Using the system is fun
- I enjoyed using the system
- Completing the tasks using the system in enjoyable

Intention to Use

- I intend to use Augmented Reality in the laboratory in the future.
- If the system was available in the laboratory I would use it.
- I would recommend the system to a college.

Cybersickness symptoms: nausea, increased salivation, sweating, dizziness, vertigo, stomach awareness, burping, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating, fullness of head, blurred vision.

C. Case Study Results

Pre-questionnaire

All four participants had between 18 to 30 years of age, neither of them had experienced with augmented reality before. The participants had somewhat different backgrounds, with different levels of education and fields of study: two participants had a master's degree, one a bachelor's degree and one high school, two were from engineering, one from chemistry and one from other field of study. Regarding the time at the current job positions, two participants had between one and two years at the current job and other two were at that job position for more than two years.

Figure 5 shows the level of excitement of the participants towards the experiment and the expectations level regarding augmented reality in the laboratory. It is possible to see that not all participants were excited with the experiment, nevertheless the expectations for AR were overall positive.

Fig. 5: Level of excitement regarding the augmented reality system experience and expectation regarding AR in the laboratory

Post-questionnaire

Regarding the the application, all participants followed a troubleshooting workflow (related to the troubleshooting of laboratory equipment), one participant also followed a development workflow (related to the analytical development area, which contains most of the workflows used in the laboratory). As for the features, all participants used the step-by-step guide, one participant also consulted a document, and another a diagram view. There were two participants that did not use any auxiliary feature. The created/modified by feature was not used by any participant.

Speech Recognition: The 3 participants that experimented the speech recognition feature were asked to evaluate their experience, the results are presented in table 6.

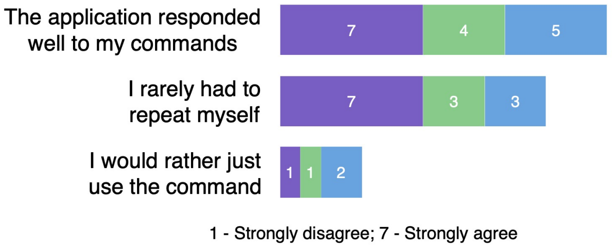

Fig. 6: Participants evaluation of the speech recognition feature

The results show that the participants would rather use the speech recognition than the glasses controller to navigate the application, even though the need to repeat commands was not infrequent for two of the participants. The 1 participant that did not use the speech recognition was asked to rate the reasons for not using it. The higher rated reasons for not using the speech recognition were that the participant did not like the idea of speaking to a device and that he/she did not want to disturb the colleagues in the laboratory.

Cybersickness: Regarding cybersickness, one participant did not report any symptoms. Symptoms reported by other participants include mild and/or moderate difficulties in focusing and concentrating, and blurred vision. Being that the participants did not report any severe symptoms, it is not likely that these symptoms had a considerate impact on the results. Although they show the flaws in the HMD hardware and advocate for its improvement.

7-Point Likert Scale Questions: The participant rated each statement with a value between 1 and 7, 1 meaning strongly disagree, and 7, strongly agree. Figure 7 shows the average score for each variable and participant. These averages were computed by using the results from each statement related to the selected variable (the statements per variable can be found in section VI-B).

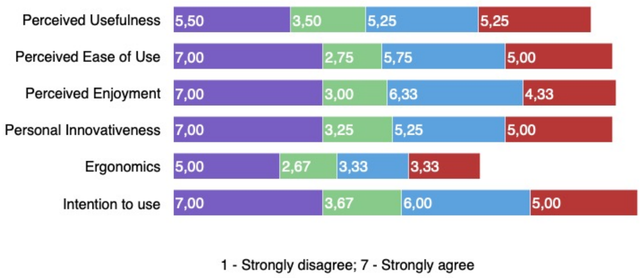

Fig. 7: Average response for each variable and for each person

Looking at the results the variable that scored the highest sum of averages was intention to use, this is a good result since it means that the analysts intend to use the augmented reality system in the future, although there was one participant whose average was still slightly bellow the median. The variables perceived ease of use, perceived enjoyment and personal innovativeness all scored fairly similar and overall good results. The results for ease of use reveal the intuitiveness of the applications design. Perceived enjoyment and personal innovativeness are more related to personal traits, although they can influence and be related to other variables.

Perceived usefulness had an overall score a little bit lower than the previous three variables. For this variable it is important to evaluate the individual statement results. The results show that the users did not agree with the statement that says: “the system allows me to accomplish tasks more quickly”. Another statement that also got a lower score was: “the system improves my productivity”, which can be related to the previous one since productivity can be interpreted as a rate of work per unit of time. But the other two statements that evaluate perceived usefulness got high ratings. These are: “using the system improves my job performance”, and “the system is useful in my job”. From these results one can conclude that the analysts did find the system useful, just not in terms of time saving.

The variable that scored the lowest sum of averages was ergonomics, this variable was related to the smart glasses used. The fact that the wearable device is not comfortable can greatly impact the users intention to use the device. This is an aspect of head-mounted devices that needs to be improved in order to accomplish a greater acceptance of the technology.

It is possible to see that although the results are overall positive there is still much room for improvement. Putting these values in percentage and averaging all participants, the intention to use the system would rate 73.61%. These results can be due to the personality of the users, which there is some evidence of in the results: participants that rated lower in personal innovativeness also gave lower ratings to the other categories. Other cause could be the fact that the analysts are not used to this type of system which has a learning curve despite its intuitiveness, more time spent with the system might have had a positive effect on the results.

Additional Comments: Two participants added an additional comment at the end of the questionnaire. Both comments are included here:

1) “The glasses/application are very interactive, easy to use and the voice recognition is quite good. The key word for the glasses to respond to the command is something that should be modified, so that the glasses are not always asking to repeat themselves, because sometimes the need arises to talk to a colleague in the lab.”
2) “I have found the glasses to be a useful tool in our day to day problem solving. It is easier to follow the workflows on the glasses than on the computer. Because we can stand by the equipment and follow the workflows while we do the procedure.”

Regarding the first comment, The key word asked by the user was integrated in the system prior to the following participants experiment. The second comment states that the application was able to solve one of the disadvantages of the previous method, expressing that augmented reality applications is a more portable tool than the convectional one, and that it helps with the worker’s daily tasks.

VII. CONCLUSIONS

This work proposed an augmented reality application to be used in the analytical laboratory of a pharmaceutical company with the objective of facilitating the analysts work by providing an easier and more flexible way of following procedures.

The proposed application allows the analysts view the procedures in a step-by-step guide, with the instructions for each step being displayed in the analysts’ camp of vision through the use of smart glasses. These procedures are based on workflows that are retrieved directly from the company’s data base and are then transformed into the step-by-step guides by the application. Another features were added to the application in order to further help the user with the procedure, such as the possibility of consulting documents and who created the workflow.

To increase the flexibility of the solution, the application features hands-free navigation, which was accomplished by implementing two services: speech recognition, that allows the users navigate the application using voice commands; and gesture recognition, that gives the user the possibility of navigating the procedure using gestures. These types of navigation allow the user to keep doing a task while still consulting the procedure, which was not possible before, when the analyst had to consult the procedures in a small computer. It also eliminates the possibility of cross-contamination considering that the analyst does not have to touch the glasses while doing the procedure.

The application running on Moverio Epson BT-300 smart glasses was evaluated by the analysts through a case study conducted in Hovione's analytical laboratory. The analysts tested the application following troubleshooting of equipment and analytical development workflows in a real case scenario. Feedback from the case study led to the conclusion that the system is a valuable asset in the laboratory and that it accomplishes its purpose of helping the analysts with their job, meeting the initial objectives of this thesis. Nevertheless, there are many aspects that can be improved to further improve the usefulness of the application and to increase user acceptance.

A. *Future Work*

The application could be turned from a view-based AR application to a triggered AR application. The start of procedures could be triggered by using markers or by detecting the equipment in the laboratory, creating an even more interactive application and eliminating the time to search and select the procedure. It could also be expanded to contain other procedures from different sources. The pharmaceutical industry is still very paper based and is trying to shift to digital formats. Another function could be to use the application for training purposes by providing more detailed information on how to perform the procedures.

The case study had the participation of only 4 analysts. Future research could replicate the study with more analysts to get a more representative population. With a greater sample size a statistic analysis could be made and the hypothesis of the technology acceptance model could be proved or disproved.

The object detection models could be improved in order to increase detection accuracy. This could be achieved by gathering a larger dataset, by training the models for a longer number of training steps, or by changing the models architecture. The speech recognition could also be improved by training a more specific model, using a dictionary containing only the words that the application has to recognize.

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