

# **BACHELOR PAPER**

Term paper submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Engineering at the University of Applied Sciences Technikum Wien - Degree Program: Mechatronics/Robotics

## **Digital Shields at the Digital Miniature Factory**

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Vienna, 30th March 2023

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## **Abstract**

This project of investigation done in the Digital Miniature Factory (DMF), more concretely in Fachhochschule Technikum of Vienna, deals with the creation and implementation of the Digital Shields. The Digital Shields are some digital barriers created with augmented reality, that help the user to check the security of the factory by using an electronic device.

When the mobile robot enters in an area defined with a Digital Shield, the safety of that station would be compromised, forcing the PLCs to interact. Those areas are considered as possible places of collision between the mobile robot and the stations, or between 2 different stations. To avoid that, the PLCs of each station will be programmed to make the stations stop when they detect that the mobile robot is inside the dangerous area. Apart from stopping the movement of the stations, the augmented reality device, will show the user where the collision is given and will show a notification showing that an error has happened. This way, it will make easier for workers to see the failure that his factory has, to be able to make it work again safely.

**Keywords:** Augmented Reality, DMF, Digital Shields, Stations, Mobile Robot, PLC

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# 1 Introduction

The Internet of the Things (IOT) is a topic that it is being heard more and more over the years, with the development of new technologies, by making physical objects connect with the network [1]. A good example of it is Augmented Reality (AR), that besides from the entertainment use than we can give to it, it is also important to mention that it is useful to use it in the workplace [2].

The project will be done in the Fachhochschule Technikum of Vienna, more concretely in the Digital Miniature Factory (DMF), where it simulates in a small scale what could be implemented in a factory in real life. This simulation will help to find out if the factory has control over all the situations that can happen in real life.

For now, there is still no safety to control all the stations and the mobile robot that is interacting with them. For all this reasons, new Digital Shields will be applied with augmented reality, as barriers to not let the stations go through. Once the safety is solved, we could start thinking about implementing it in the real world.

## 1.1 Motivation

The pursuit of knowledge to know how augmented reality works, has led me to investigate and to realize my thesis about it. Besides, this topic was good to work with, to put together and to gain new knowledge in different areas related to my career. This has led me to inspire myself to do this project with more passion.

AR is an interactive version of the real world, where new digital interactions are possible [3]. Using an electronic device such as a phone, a tablet, or virtual reality glasses allows you to have a 3D vision of your surroundings. In this 3D vision there is a combination of the physical world and the digital world created by the user [4].

In the recent years, with Industry 4.0 is increasing the number of companies that are using AR, thanks to the advantages that gives humans to use it [5]. It helps with the interaction of the different parts of the factory, by making it easier to control it and to increase the productivity.

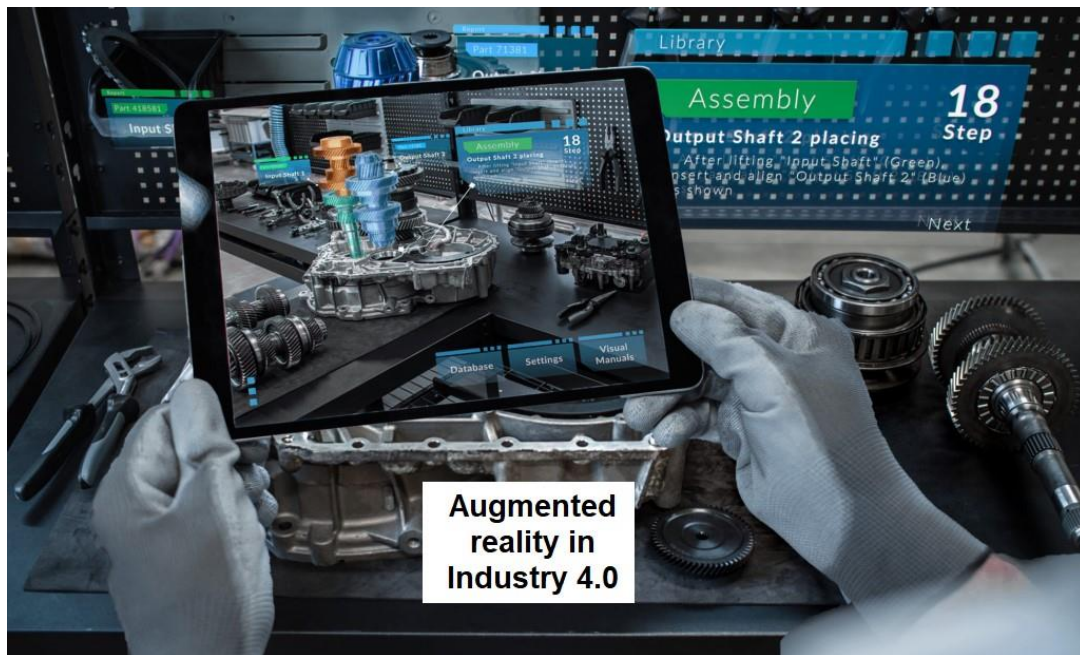


Figure 1: Augmented Reality implemented in a tablet ( Modified [6] ).

The department of Mechatronics/Robotics is now working with the DMF, where you can find a mobile robot that goes from one station to another. They are 5 different stations connected to each other: Sorting, Bad Parts Storage, Storage, Conveyor and Arno.

The aim of this factory is to distribute different color-customized 3D printed carabiners that are picked by the mobile robot. The mobile robot will follow the line till it arrives at the station that is needed considering the different individual customer requirements [7]. The robot will be able to stop at that point, but it could happen that the station could collision with it. That is why it needs to be controlled the safety of it, by working with augmented reality.

### Product: Carabiner

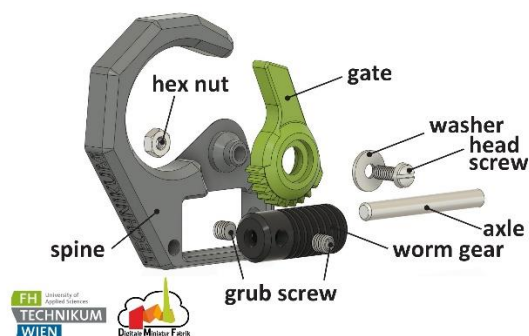


Figure 2: Carabiner used in the DMF.

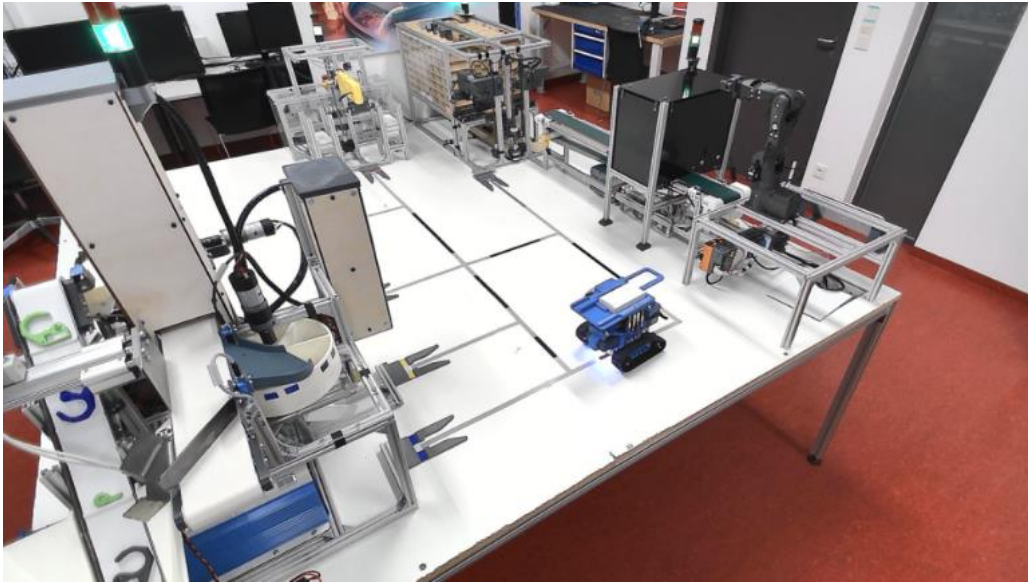


Figure 3: Image of the DMF

The AR that we are going to use for the safety of the factory, is applied by Digital Shields. Those are some shields that would work as barriers, to not allow anything going through. The program that I am going to use for that, it is called Vuforia Studio [8]. It allows to create a visual representation of a 3D model of the different stations, adding to it the Digital Shields. When the different stations try to go through the shields, it would interact with it.

To implement these shields, the exact position of the robot will be needed all the time. This way the location of the robot will be known and the positions that the robot needs to be aware. For that, the collaboration of Mrs. Celia Pérez will be needed, also an Erasmus student at the university of Vienna, that is working with the mobile robot, to have the right position each time.

Finally, the different PLCs of each station will be programmed to stop the movement when the station tries to get through the shield. All of that will be possible thanks to ThingWorx, the communicating system that the hole fabric has. It will send the signals to make the stations to stop and to ensure finally the safety of the DMF.

## 1.2 Methodology

The type of academic work that I am going to be realizing for this thesis is quantitative. This means, that it is a structured content analysis of the Digital Shields. The information used is shown in numbers and amounts, making it measurable. It involves collecting and analyzing numerical data to deal with those results by making predictions and testing relationships to finally obtain an outcome. These predictions are usually made in a small scale, to be capable



to apply the results in a larger scale and then when the results are accomplished to generalize them.

The quantitative research it is usually made by scientists to understand better the different phenomena that happens in our world. It helps us to find different answers to the different unsolved questions by involving a sample of people or a sample of proof.

### 1.3 Problem statement

The DMF has several problems, or implementations that could be fixed. The main trouble on which this project will be based on is the safety. The mobile robot and the stations are not even defined in augmented reality, so by now we are not able to see the collisions that could happen. To solve this first problem, we will have to define the 3D model and the digital shields by working with Vuforia Studio [9].

The Digital Shields are the ones that will control the collision problem, by creating a barrier that won't let the robot and the stations touch. To define these barriers, we will need to look for safety distances that could be applied in different stations in real life and implement them into our miniature version of the factory [10]. This way, we will leave some free space between the mobile robot and the stations to prevent the collision, so that when it stops no problem will occur there [11].

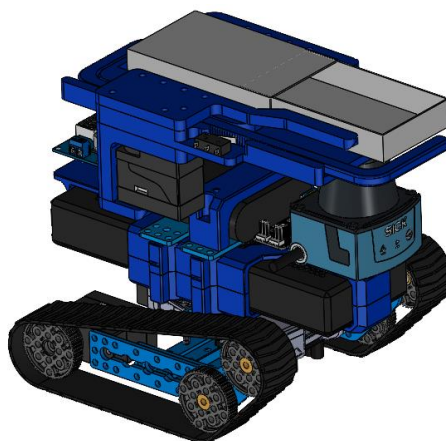


Figure 4: Mobile Robot of the DMF.

They are several ways to solve the problem that could happen with the safety distances. The first way and one of the most used one, is to implement it by using laser sensors, to know where not to go and to stop at this point. We don't have laser sensors at the DMF, so the other

option would be implemented, by knowing the exact position of the mobile robot. Using the position, we could create our different barriers and when the different coordinates could collision it would stop the PLCs of that concrete station.

## **2 State of Art**

The Digital Shields are several barriers created by humans to help us with the safety in the last years [12]. The name of Digital Shields comes from the barriers created in north Wellington (USA), to prevent accidents with the workers that worked near the tracks of the train [13]. With this idea, I will base my thesis on trying to do the same in the DMF with the mobile robot.

### **2.1 Epistemological interests and theoretical frameworks**

Augmented reality is an interactive version of the real world, where new digital interactions are possible. This technology can be very useful for the safety at work, it will make the factors of risk decrease and it will prevent injuries to happen [14]. In the last years, the safety in the factories it is one of the compulsory disciplines that must accomplish. Further research [15] showed that “is crucial to guarantee the safeguard of people in different working environments.”

Nowadays in the different factories, humans and machines work together to able to execute tasks in an easier way. When they work together, they must ensure the safety and protection of the human workers. The robots have some safety sensors to indicate the risk of collision and “adapt their own Cartesian motions” [16]. This way, they prevent that a robot could collide, causing danger to the workers or even machines of the factory. The robot will move in another direction to reach his goal, or even it could stop, depending on the situation.

Besides those sensors in the robots, that help with the safety, some other systems are needed to be applied to have a better control of the facilities. The augmented reality is a good option to solve that, by creating a 3D vision of the environment. With that 3D vision, engineers can improve the efficiency of the inspection and deal with the maintenance of the different machines [17]. This way, they have the control of the position of the different objects that are in the surrounding.

## 2.2 Most Relevant Literature

This new type of Augmented Reality technology was created for the KiwiRail's Trentham to Upper Hutt, in the Wellington Region. They use those shields to make a digital twin of the environment, using a laser scanner to identify when the different drivers of the excavators wanted to go through. When they tried to go through, it would immediately stop the excavator from moving, not allowing to move more in that direction [18].

For all that to be possible, they needed to first create a 3D digital model of the whole environment of that region, so that they could implement the shields. Once they have done that, they would need to set a GPS connected to the excavator, to send the signals ordering to stop it. Knowing this, they could be able to have the exact position at each time, to prevent accidents to happen.

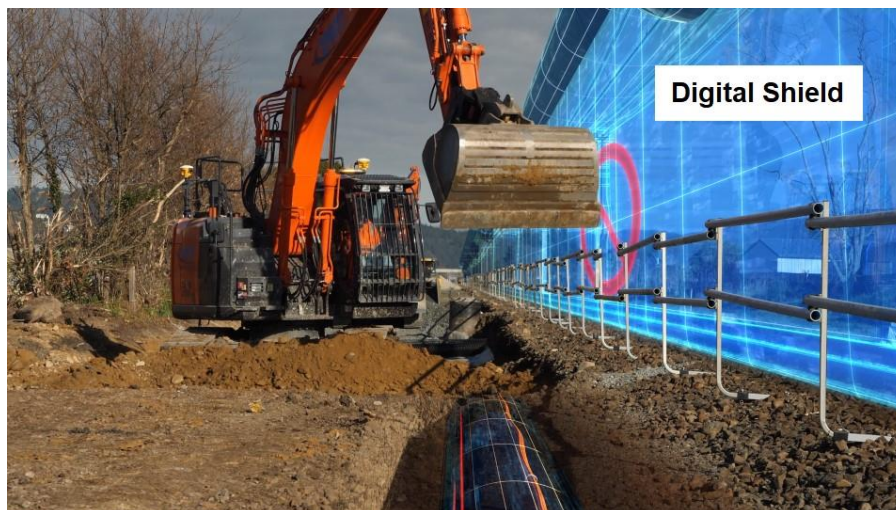


Figure 5: Digital Shields in the train near Wellington (Modified [18]).

## 2.3 Literature applied to my own project

For my thesis, I will apply the same method than in the train in Wellington, so that the DMF can work safely. The Digital Shields and the 3D model will be created the same way, but this time with the physical environment of the surrounding of the factory. The GPS that they used, will be for us the ThingWorx program. Finally, the laser scanners won't be needed for it, but the exact coordinate from the mobile robot will be always needed.

## 3 Development

First of all, to realize this thesis I will start with the creation of the 3D model of the different stations, including to it the Digital Shields. For that, they are different options to do it, but the most used ones are the ThingMarks [19].

### 3.1 ThingMarks

The ThingMarks are unique identifiable markers that the Vuforia View app can recognize. Each ThingMark, is associated with one or more different experiences that have been created with the Vuforia Studio app [20]. To be able to make it work correctly by scanning it with the tablet, it should be written in the Vuforia Studio app the number of the ThingMark, so that or project will be associated with it. The ThingMark used for the stations of the DMF, that will show the safety areas on it is the next one:



Figure 6: ThingMark used for the Digital Shields in the DMF.

### 3.2 Digital Shields

The Digital Shields will represent the limits of the security barriers where the robotic arms of the different stations can't go through. From all the different stations of the DMF (Arno, Storage, Conveyor, Sorting and Bad Parts Storage), the collision mentioned can only happen in the Storage, in the Conveyor or in the Bad Parts Storage.

Different forms and sizes will be given, according to the area where the collision could happen. These forms are CAD models that will be created with the application of Creo Parametric 9.0.0.0 [21], considering the different measurements of the different stations.

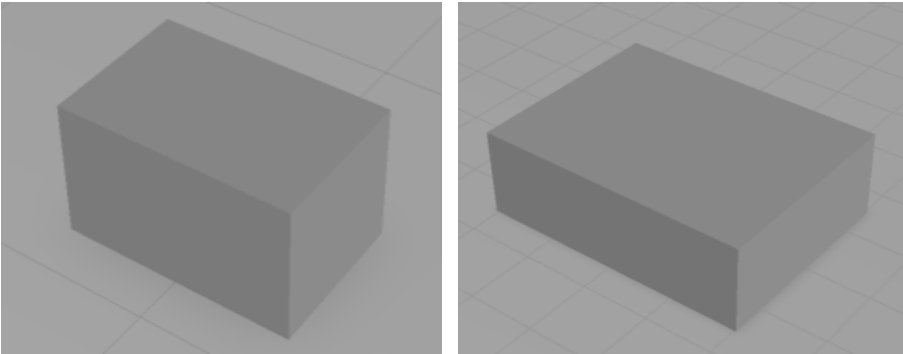


Figure 7: CAD models of the Digital Shields.

These models will be created with a digital twin of the environment [22], making the safety areas appear once the ThingMark is scanned. When it has entered in one DS, the red arrows will appear indicating that the station has passed the safety area limits and is not safe anymore.

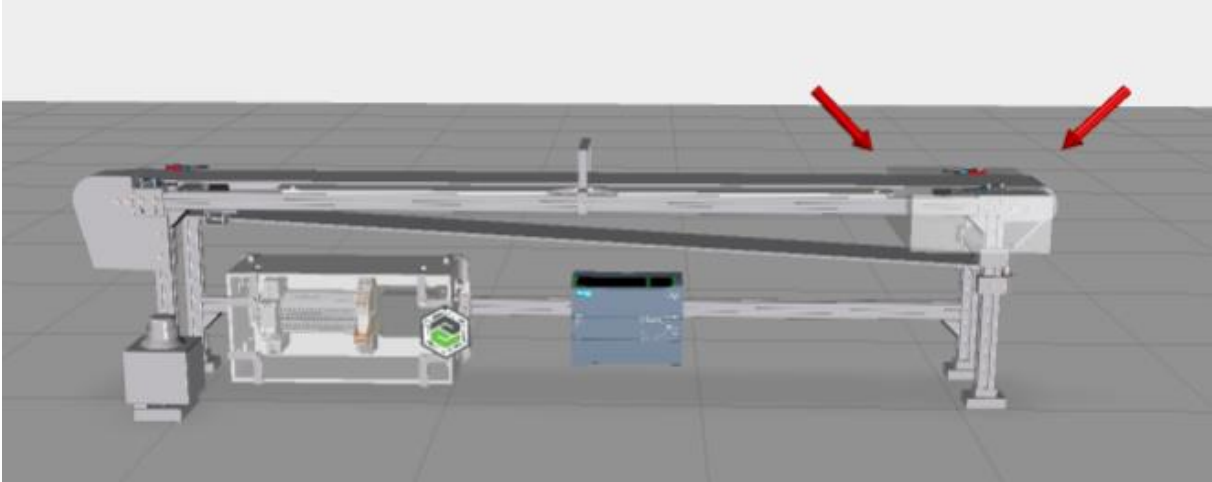


Figure 8: Digital Shield Model of the Conveyor Station.

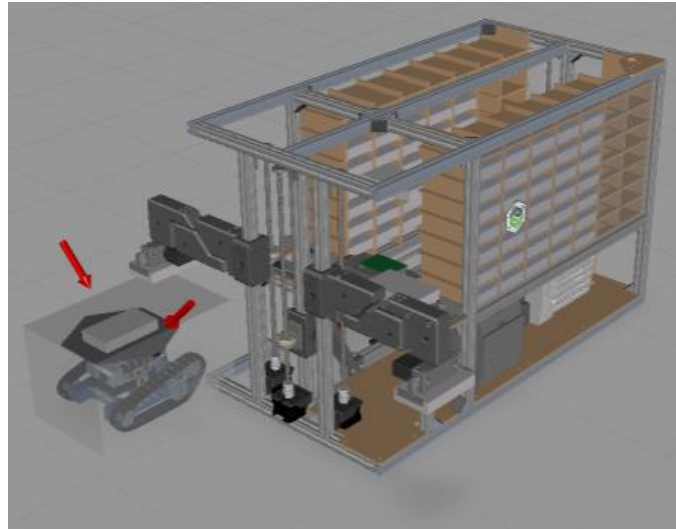


Figure 9: Digital Shield Model of the Storage Station.

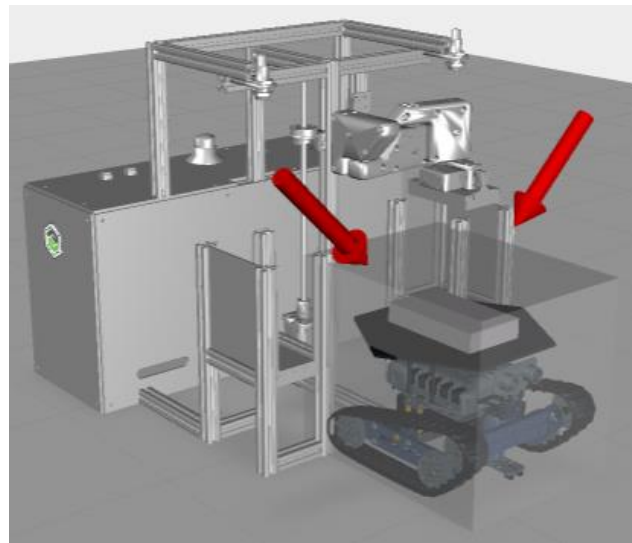


Figure 10: Digital Shield Model of the Bad Part Storage Station

### 3.3 Vuforia Studio

Once the visual representations are created, we need to associate it with the real X, Y and Z coordinates, so that it shows caution signals because it had entered in an unsafety area.

The X and Y coordinates will be given by the actual position of the mobile robot in the factory. These variables have been created by Mrs. Celia Pérez in the KepserverBasedAsset in ThingWorx [23], which is a physical asset. First, the mobile robot will be the one who will send

to ThingWorx the X and Y values, called odom\_x and odom\_y. Then, ThingWorx will be connected to Vuforia Studio, so that it can be programmed with that exported values, called cord\_X and cord\_Y, as it is shown next:

```
var cord_X = $scope.app.mdl['KepserverBasedAsset_DMF_MobileRobot'].properties['odom_x'];  
var cord_Y = $scope.app.mdl['KepserverBasedAsset_DMF_MobileRobot'].properties['odom_y'];
```

Given the values of cord\_X and cord\_Y, there will be used to define a range of values where the station can collision with the robot. They are 2 different stations that could have this type of collision: the Storage Station and the Bad Parts Storage Station.

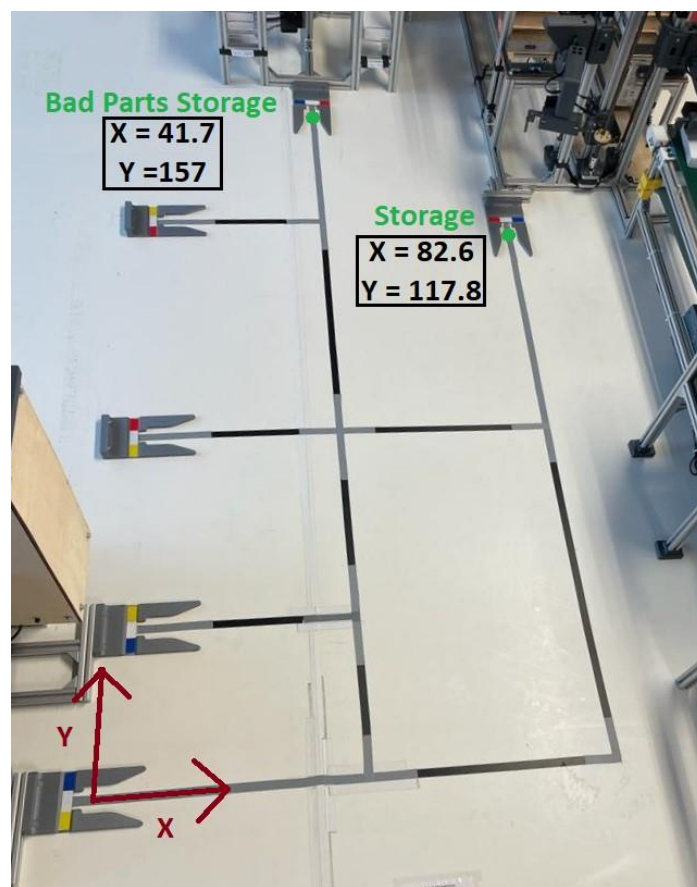


Figure 11: Coordinates of the mobile robot

The values mentioned above are the values that the robot has when it has arrived at the station. With these values, it can be now defined a range where it is considered that is inside one DS. The range in X could differ  $\pm 10$  centimeters, due to the small errors that the mobile robot could have in the movement. However, in Y it could also differ  $+10$  centimeters due to the movement, but also in  $-35$  centimeters to prevent the robot entering in the collision area. This is because it is important to consider that when the robot enters in the station, the movement is in Y and in that time, it could happen a possible collision with the robotic arm of the station.

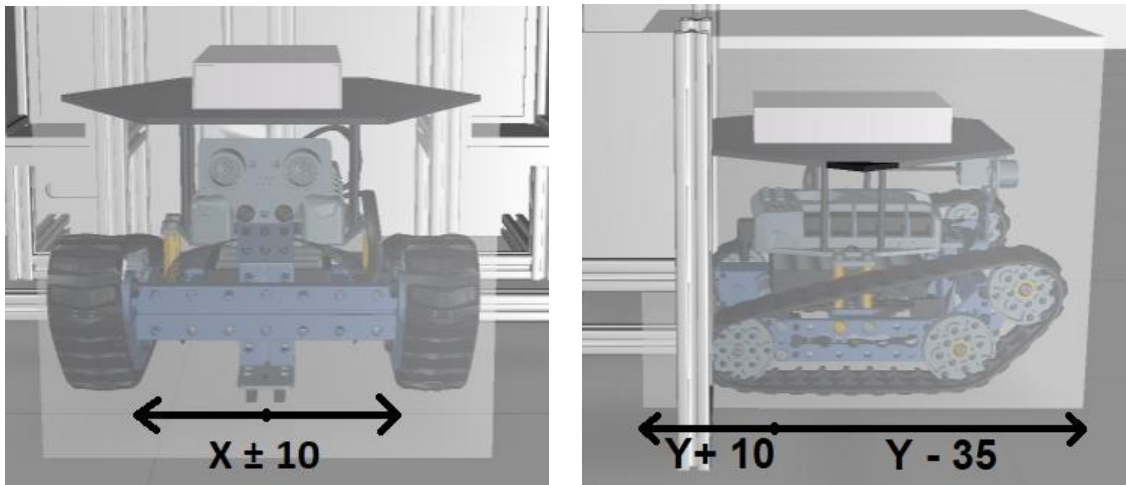


Figure 12: Range acceptable in the coordinates X and Y

The Z coordinates will be also needed, but now it corresponds to the height (given in meters) of the robotic arms of the different stations. Two different types of collision could happen, the first one is between the mobile robot and the robotic arm of the station and the second one between the robotic arm of the station and another station. The first case, it will correspond to the Storage Station and the Bad Parts Storage Station and for the second one, the Conveyor Station.

In this case, the Z values will be given by the PLC to the Asset\_DMF\_DigitalShield in ThingWorx, which is a virtual asset, to variables called Bad\_Parts\_Storage\_Z, Storage\_Left\_Z and Storage\_Right\_Z. Then, ThingWorx will be connected to Vuforia Studio, giving to it the name of cord\_Z. Further on, a better explanation will be given of how these variables should be created.

The Vuforia Studio app with the variables exported will be programed this way:

```
var cord_Z = $scope.app.mdl['Asset_DMF_DigitalShield'].properties['Bad_Parts_Storage_Z'];
var cord_Z = $scope.app.mdl['Asset_DMF_DigitalShield'].properties['Storage_Left_Z'];
var cord_Z = $scope.app.mdl['Asset_DMF_DigitalShield'].properties['Storage_Right_Z'];
```



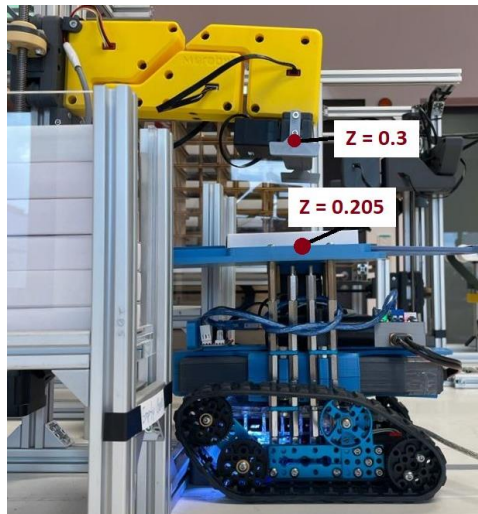


Figure 13: Z coordinates of the Bad Parts Storage

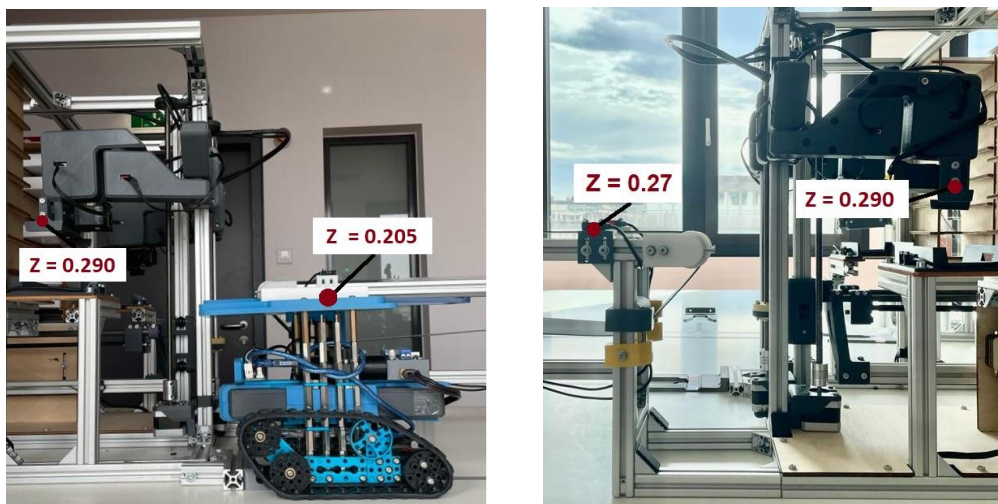


Figure 14: Z coordinates of the Storage (Left) and Z coordinates of the Conveyor (Right)

The coordinates shown in the pictures above, are the possible positions where the robot can go, one is the initial position and the other one is the position where the station takes or puts the box. Once known the minimum values, the collision area could be defined with range from 0 to 0.206 in the Bad Parts Storage and in the Storage. On the other hand, in the Conveyor, due to the different minimum value, the range will be from 0 to 0.275. The position where it takes or puts the box is a little bit lower of the maximum value of the range taken, due to the delay that ThingWorx has when it sends the values.

Now that the width, height and length of the DS are known because the range of the values of the X, Y and Z are given, a new boolean variable will be defined. It will have a value of 1 if it has entered in a DS, making the PLC stop, showing a message error in the tablet and appearing 2 red arrows indicating where collision comes from.

### 3.4 ThingWorx

In ThingWorx, new variables have been created in the Asset\_DMF\_DigitalShield, which is a virtual asset. These variables will have different purposes, but all of them will be to transfer the values from one program to another (to Vuforia Studio or to the PLCs).

The created Z coordinates will be the ones that the PLC will send to Thingworx and after that ThingWorx will send it to Vuforia Studio, to know if it had entered in a DS, as it is already explained before.

Name	Actions	Source	Default Value	Value	Alerts
# <u>Bad_Parts_Storage_Z</u>		BadPartsStorage...		0.27000001072883606	0
# <u>Storage_Left_Z</u>		Storage.Storage...		0.2800000011920929	0
# <u>Storage_Right_Z</u>		Storage.Storage...		0.2800000011920929	0

All of them have a remote connection with the PLC, indicating with a thumb up that the connection is successful. Each time that the robotic arm moves, the position will be actualized and it will be given in meters the actual position.

There will also be 3 boolean variables, called DS\_Bad\_Parts\_Storage, DS\_Conveyor and DS\_Storage, that are the ones responsible to make the PLC stop when they have the value of true. The value of true/false it will be given from Vuforia Studio to ThingWorx when it has entered in the unsafety area and then in ThingWorx it will be programmed to make it stop.

### 3.5 Tests and Results

Finally, to see if all the programming works well together and it does what it was expected, some tests will be made. First of all, the visualization of the DS in the initial position of the stations will be checked, to know where the area of the shield is located.

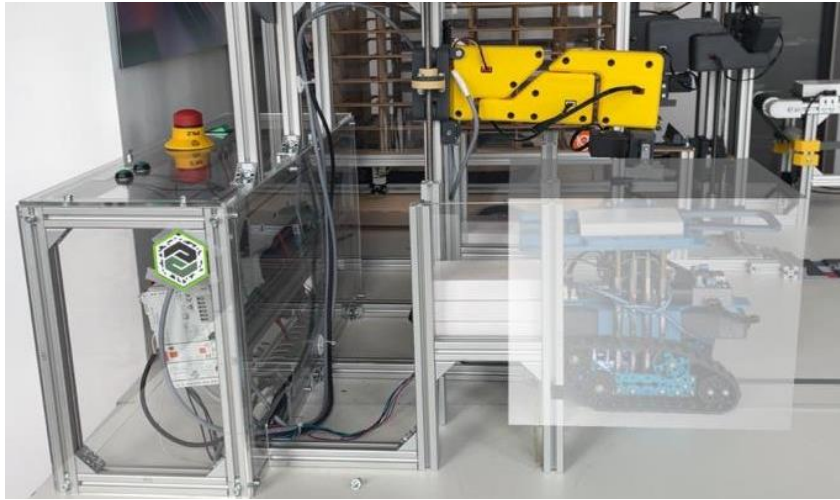


Figure 15: DS of the Bad Parts Storage

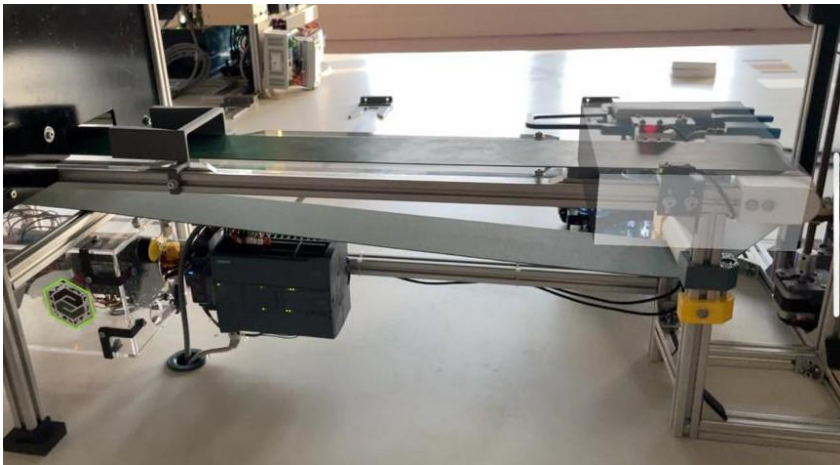


Figure 16: DS of the Conveyor



Figure 17: DS of the Storage

Then, it will be checked if it appears the different DS when the robotic arm of station has entered in one.

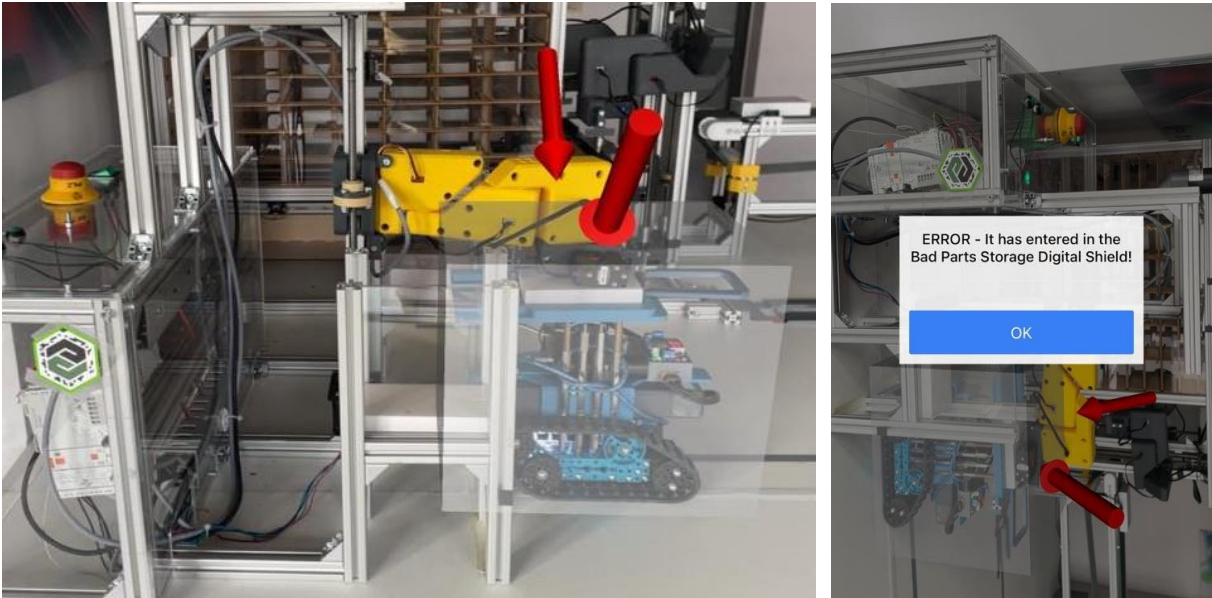


Figure 18: Entered in the DS of the Bad Parts Storage

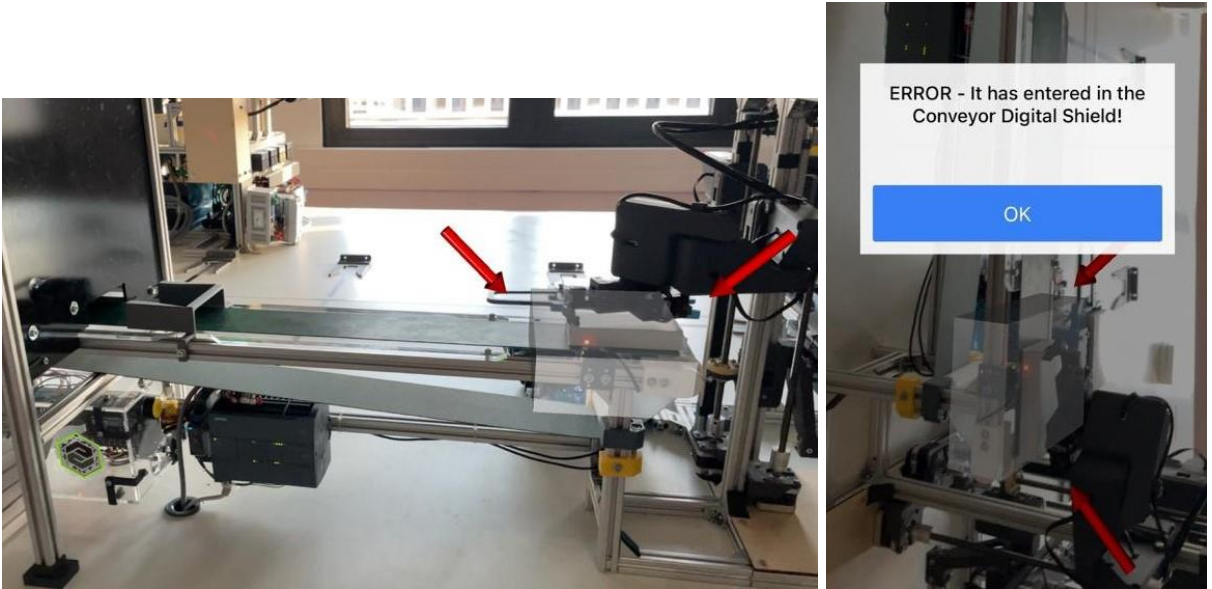


Figure 19: Entered in the DS of the Conveyor

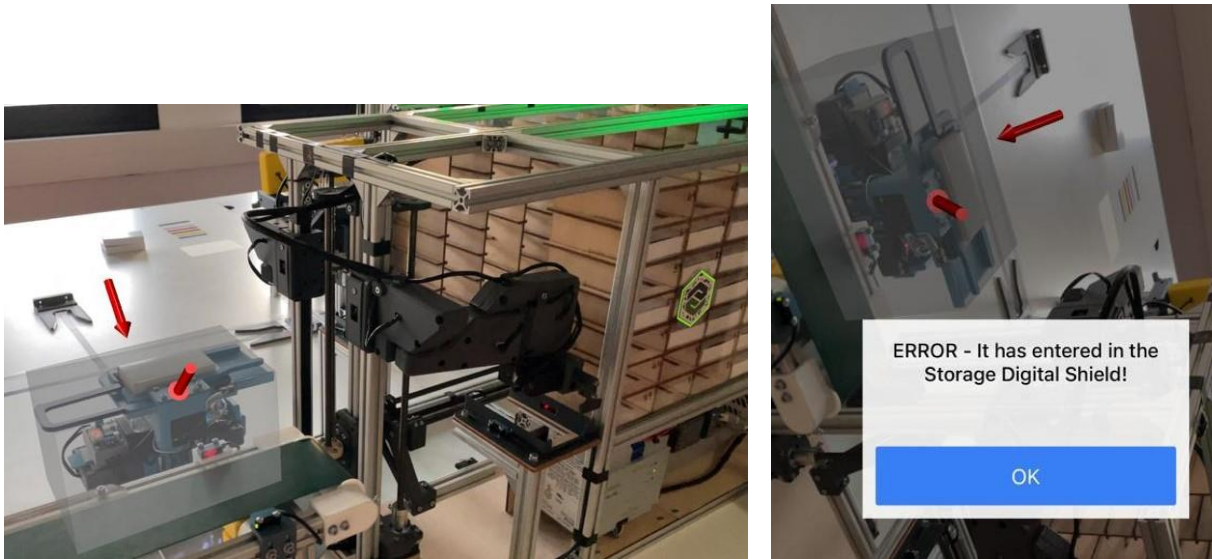


Figure 20: Entered in the DS of the Storage

The results obtained were the expected ones, because it notifies the user that an error is given and it shows the area where the collision is happening. Because of that, the conclusion obtained is that the things programmed in Vuforia Studio and ThingWorx are working as they should.

### 3.6 PLCs

The PLCs (programmable logic controller), that are usually used in the industrial environment will be the ones that will make the station stop when it is needed. In the DMF, each station will work with a different brand of PLC, these are the next ones:

- Storage: Wago
- Bad Parts Storage: Wago
- Sorting Station: Siemens
- Conveyor: Siemens
- Arno: B&R

Not all the PLCs will be needed for this Thesis, only the ones that will make control the safety of the station. Those stations are the Storage, the Conveyor and the Bad Parts Storage. For the Conveyor, in his own PLC it won't be necessary to program nothing, because the Z values will be given by the robotic arm of the Storage and that will be the one who will need to be

stopped in case of collision. Because of that, the only brand that it will be needed to programmed is in Wago that works with the program e!COCKPIT.

The movement that was till now programed in the different stations is a movement that is safe and it doesn't collision with nothing. To test if it works and it stops before a collision is given, the values of the Z coordinates need to be changed.

The ones that were already given are the next ones:

```
zPickMobileRobot : INT := 200;  
zPlaceMobileRobot : INT := 208;  
ZUp : INT := 300;
```

Figure 21: Z values of the Bad Parts Storage

```
zPickMobileRobot : INT := 205;  
zPickConveyor : INT := 270;  
ZUp : INT := 290;  
zInputComp : INT := 238;
```

Figure 22: Z values of the Storage and of the Conveyor

The new Z values will be reduced to the half, to ensure that the collision will happen and that the PLCs will stop when it has entered the unsafety area. The values considered are the next ones:

For the Bad Parts Storage: zPickMobileRobot : INT := 100;

For the Storage: zPickMobileRobot : INT := 105;

For the Conveyor: zPickConveyor : INT := 170;

### 3.7 Future development with the PLC

In a future development, new variables will be defined in the PLC, that will be programmed as emergency values, to get the station that is in danger of collision to stop. Three new variables will be created for that, each one for one of the stations that could have problems with safety. For that, the boolean value that is now sending Vuforia Studio to the PLC, will be the one that will cause to the PLC of the station, when it has the value of 1 to stop. The value of 1, will mean that it has entered in a DS and on the contrary, the value of 0 is that it hasn't entered.

Right now, as the Z values of the stations have been changed to half, the stations will always enter in that DS. In a future, it will be created a way to make the PLC stop, to create a safety environment in the DMF.

In real life, this type of collision would not be something that it would usually happens. This problem could be given, for example, when a technical problem happens and the station is not answering and doing what it should. To prevent that, all factories need to have some safety measures, to ensure the safety of the workers [24].

## **4 Conclusions**

In conclusion, this thesis has given me the opportunity to learn much more about augmented reality and all the different applications that it could have nowadays. In particular, to understand better, how the physical and the digital world could cooperate to show a 3D image, so that the people could better understand what it is happening in the factory.

I explored many ways of how the safety could be implemented in the factories nowadays, by having a range of options, thanks to the different technologies that we have. That brought me, to investigate more about the different uses that it gives this type of technology in the industries.

Furthermore, it helped me to gain knowledge about the correlation that it has the AR with the digital and the physical world. Making me learn how the different information is transmitted and how it should be connected to make it work correctly.

Finally, it helped me to understand a new technology in a dynamic way, thanks to the challenge that this project was for my carrier. Being able with it to see the good future that this technology will have, thanks to the interactive uses that it has.

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## List of Abbreviations

DMF	Digital Miniature Factory
AR	Augmented Reality
DS	Digital Shields