

**UR robot scripting and offline programming in a virtual reality environment**

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# 

# Abstract

# Certification

# This thesis has been submitted by Alberto Zafra Navarro and Jorge Guillén Pastor to the University of Skövde as a requirement for the degree of Bachelor of Science in Production Engineering.

# The undersigned certifies that all the material in this thesis that is not my own has been properly acknowledged using accepted referencing practices and, further, that the thesis includes no material for which I have previously received academic credit.

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# Introduction

### Overview

The next report presents a different way of programming collaborative robots, using virtual reality. For this purpose, software has been developed using the Unity platform and employing the virtual model of the UR10e collaborative robot. By implementing this alternative form of programming, the programming time will be reduced. Besides, it will decrease the training required for the operators performing this job due to a more intuitive and natural way of coding.

### Background

Nowadays, the use of collaborative robots has become more popular. These kinds of robots are suitable to work near humans in a safe manner, whereas classical industrial robotic arms require fences around them and other safety measures. While much less complex safety protocol is needed to program collaborative robots, other variables might affect the availability of the robot for programming and testing current and new features, as well as modifying/optimizing existing robot programs. Virtual Reality (VR) opened the doors to safe, independent of real-world factors, way of programming robots. The main purpose of this project is to introduce VR programming to a certain collaborative robot and to demonstrate the potential of using this kind of virtual environment.

# **Problem Statement**

##### Why is necessary?

As the use of robots both in industry and in people's daily lives increases, the position of robot programmer is becoming more and more requested. However, with today's software, a lot of experience is required.

In the existing framework of robot programming, we can find different programming methods.

Lead-through programming consists of the use of the teach pendant for on-line moving the robot. Despite the simplicity of the concept, some programming skills are required and teaching trajectories in this way can be tedious and especially time consuming.

Walk-through programming consists in letting the user physically move the end-effector of the robot through the desired points so that the robot records those positions. Although with this method the programming time consuming can be reduced, a huge investment is needed to equip the robot with the measuring system required. In addition, the user's comfort may be compromised by direct handling of the robot. (Villani *et al.*, 2018).

Offline Programming consists in the remote simulation of the task in a 3D model of the complete robot workcell. After simulation and testing, the program is exported to the physical robot. In spite of it being a commonly used method, it is time consuming and non-intuitive.(Burghardt *et al.*, 2020).

Programming using virtual reality and digital twins is the programming method that will be covered in this thesis. It consists of the virtual simulation of the robot and workcell where the user can virtually interact with the robot, teaching the movements and paths it should follow. It is an intuitive and time-saving programming method where a lot of experience is not required. Besides, it contributes to increasing the safety and mental comfort of employees in real conditions of cooperation with robots. (Oyekan *et al.*, 2019), (Burghardt *et al.*, 2020).

Due to those inconveniences, this project has the aim to create a program that allows the user to code in a simplistic and low time-consuming way, fulfilling all the gaps of the currently released softwares.

##### Why VR?

First of all, before determining why this kind of technology is chosen, it is necessary to outline those tools.

###### Virtual Reality (VR)

According to the Chambers dictionary, Virtual reality (abbreviation VR) is a computer simulation of a real or artificial environment that gives the user the impression of actually being within the environment and interacting with it, without the need of intrusive technology. (*Chambers – Virtual Reality*, 2021)

This means that the popular mentality that VR must necessarily be generated through a headset is no longer true.

###### Augmented Reality (AR)

Augmented reality (abbreviation AR) an enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device, as is stated in the Merriam-Webster dictionary. (*Augmented Reality | Definition of Augmented Reality by Merriam-Webster*, 2021)

In this case, augmented reality is not needed to be generated as an immersive experience, everyone with a single smartphone could be able to experience the AR. In spite of the VR.

###### Mixed Reality (MR)

The real environment and the virtual environment (also called virtual reality, VR), are the two extreme points of the reality-virtuality (RV) continuum. All the information is either real or virtual. Everything in between those extremes incorporates virtual and real elements and is called mixed reality (MR). (Egger and Masood, 2020).

##### VR is selected.

For this project, the use of VR technology has been selected over AR and mixed reality.

VR glasses permit work remotely, making it possible to operate outside the work area. In addition, they facilitate working with a partner online, which can be very advantageous due to the current pandemic situation.

Another important factor in the choice of VR glasses is the price. Nowadays VR technology is more developed than others, especially in the gaming industry. Therefore this technology has reached a more affordable price. (Ghrairi *et al.*, 2018). This project wants to reach all companies, both large and small, that is why VR technology has been selected.

Moreover, Augmented Reality and Virtual Reality have been around for quite some years, but while virtual reality has evolved quite well and also made the step forward into industry, augmented reality still stays behind.(Braitmaier and Kyriazis, 2011).

Furthermore, in some studies in the medical area, some patients had more enthusiasm when they worked with VR. Due to this, is supposed that the workers will be more willing to work, if the task is more fun or interactive, thanks to the use of this technology.(Khademi *et al.*, 2013).

In the end, the HTC Vive Pro goggles were used due to availability.

### Outline

The aim of this section is to clarify the structure of the report, which specifies what includes each chapter and the main contents of those chapters.

Chapter 1: Introduction - The introduction identifies the topic and introduces an overview of the project. In addition, the background and some general questions are addressed.

Chapter 2: Theoretical Frame of Reference - The Theoretical Frame of Reference explains the concepts and tools used in the thesis.

Chapter 3: Literature Review - This section analyses the previous works related to the project, with the use of references and reviews the possibilities of the project by the use of past studies.

Chapter 4: Method - The next section explains the methodology taken for developing the thesis. Moreover, the most important parts, such as the development of the software, are discussed in more detail.

Chapter 5: Results - In the Results chapter the final version of the project is analysed and is determined if the thesis has achieved the desired final point of development.

Chapter 6: Discussion - This section addresses all possible external factors that may be affected by the creation of such a project. Whether it is beneficial or not.

Chapter 7: Conclusions - The Conclusions section makes an overall explanation of the final thoughts of the authors. Indicating which parts were successful and which parts could be improved.

Chapter 8: Future Work - The last section determines the work that was not possible to be achieved and the further development of the project, encouraging the reader to carry out such a development.

# Theoretical Frame of Reference

### Unity 3D and C#

Unity 3D and Unreal engine are the most used tools of choice for VR developers. In addition, the mostly used for VR programming languages are Java and C#, the later being the most used in Unity 3D. However, Unreal Engine cannot program in these languages as it is limited to C++. Due to this and the different advantages of Unity 3D, this will be the software with which we will develop our project.

Unity 3D is a multi-platform game engine developed by Unity Technologies. It offers rapid prototyping and the possibility to develop applications on different VR devices. In addition, it supports several 3D formats and has a huge assets compilation in his “Unity assets store”.(Ghrairi *et al.*, 2018), (Tanaya *et al.*, 2017).

As mentioned, Unity 3D can be programmed in both Java and C#. For the development of this project, C Sharp has been selected, mainly owing to previous experience with C and C++, the antecessors languages of C#. In addition, although both are good object-oriented programming languages, C# has a simpler and more intuitive interface and allows the use of the .NET Framework, which provides numerous valuables classes and administrations. (Ghareb, 2016).

### Collaborative Robots

The Robot term is a Slavic word for worker. But the use of its word was settled in 1921 with the play RUR (Rossum’s Universal Robots) written by Karel Kapek. Nowadays, the definition proposed by the Japanese Industrial Robot Association and the Robot Institute of America are focused on the use of robots in the industry. However, is preferred the definition of McKerrow, which states that a robot is a machine which can be programmed to do a variety of tasks and decide by himself logically according to the received data.(McKerrow, 1991).

A collaborative robot (also referred to as cobots) is a robot designed, both in its design and application, to be safe when working alongside humans. Cobots, integrated with advanced safety technologies, are designed for sharing their workspace with humans thus achieving the ‘right’ amount of automation. However, as the level of collaboration grows, the system tends to become complex. Due to this reason, the industrial application of cobots in labour intensive processes is still limited.(Malik and Brem, 2021).

On this project, the choice of collaborative robots is made because collaborative robots are becoming more prevalent in the manufacturing industry during the paradigm change to smart manufacturing and Industry.

Furthermore, the dexterity and cognitive skills of human operators and the repeatability and payload capability of the robots can be complemented and effectively integrated to achieve high productivity, flexibility, low ergonomic risk, enhanced safety, and reduced cost. The goal market share of collaborative robots is expected to grow 8000 times in the near future. This means that despite their implementation in the actual factories is low, in some years they would be a big active of the manufactories. (Zhang *et al.*, 2021).

### VR Glasses and Controllers

VR is the abbreviation of Virtual reality, which term was narrowed down relatively early since 1960. In addition the VR term began to be shaped and understood mainly as a technology that will support a different interface between the personal computer and the human user. (Arvanitis, 2019).

It was not until 1987, however, that the term virtual reality was defined in a way similar to how the technology is conceived today.

This term was coined by Jaron Lanier, c. 1987.

“An electronic simulation in which perspective images are generated in real time from a stored database corresponding to the position and orientation of the head of a user, who observes the images on a head mounted display.”

Furthermore, the commercial uses of VR are dated as far back as 1980 with the arcade video game Battlezone, this means that virtual reality is a technology that has been under development constantly since long ago. (Tanaya *et al.*, 2017).

Nowadays, the use of Virtual Reality has gone beyond the entertainment field and has been introduced into the industry. This offers new opportunities to all kinds of companies, since allowing them to interact with future models of the factories, to control and analyse the current state of it. Here is where the focus of this project is, in the use of this technology to ease the control of the current factory.

# 3. Literature Review

Nowadays, there is a trend to connect robotics with virtual reality, this is shown in numerous articles. But the main theme is the simulation of the plant (*game4automation | Simulation und Virtuelle Inbetriebnahme mit Unity*, 2021) and the telepresence. (Du, Do and Sheng, 2020).

Moreover, it is known that the training of the operators through VR is beneficial for the collaboration between them and the robot. (Hormaza *et al.*, 2019).

However, there is not so much softwares that helps the user to generate the code of the robot through virtual reality. Currently, the most important softwares that does that are robotstudio or VR Robotics Simulator on Steam, which use virtual reality technology for robot programming. However, both softwares have shortcomings. As in the case of VR Robotics Simulator, which is an extremely intuitive program and allows the simulation and programming of an industrial station. Although it is a brilliant program, it is not possible to export the generated code to the physical robot, the current program only allows the user to export the points as XML. This reduces the usage of the program to mere simulations. (*Mindrend Technologies*, 2021).

On the other hand, there is robotstudio from the company ABB, this software also has the possibility of programming robots by means of a simple interface using VR. The current software has all the proposed functionalities of the project, as could be teleport, simulation control, jog movement by the interaction with the virtual robot, ... Or even additional functionalities as an auto path generator, called RECORD. But, as it is a private software, this programme only allows the programming of robots from this company. Despite the enormous potential of this software, this fact significantly reduces the scalability of the software. (Holubek, Ružarovský and Sobrino, 2019).

Moreover, there is some previous work by the academic side related to this field of study.

First of all, the investigation group of Gabriele Bolano, made an environment used to intuitively program offline the robot trajectory and the task workflow. As stated in this article, the system proposed in that framework enables an easier and more efficient definition of a robot program combining offline and online programming methods. Using this method, the waypoints of the desired trajectory can be defined by dragging the virtual robot, avoiding the robot configuration problems. Afterwards the robot trajectories and operations could be exported in a format compatible with the open-source software responsible to control the real robot. With the possibility of simulating or modifying the current program in the same environment. However, the system developed only works with forward kinematics, does not export the program as a robot compatible software, only as trajectories in a ctraj format, and does not have collision detection. Nevertheless, the future work of Bolano's project is the same as the one of this projects. Implementing the system through augmented reality for a more intuitive and realistic visualization of the defined software. (Bolano *et al.*, 2020).

The next article presents the possibility of using VR as a supporting tool by using the offline programming method for industrial robots. It is shown how the robot’s end effector is moved through the virtual workstation to the desired position by using the haptic hands controllers and the VR glasses. Once the gripper is in the desired position, the user can create a target and, when two targets are set, the virtual robot can follow the path between them. In addition, the VR simulation is directly connected to the Process Simulate environment, which is shown in a 2D screen. The paper also discusses the possibility of connecting the VR simulation and PS environment to the physical robot. Although it is a complete project, its main objective was to use the virtual robot in the virtual environment to just teach its individual position in the PS software programming environment. Without developing a code during the simulation for later exporting to the physical robot. Moreover, it does not have a collision detection system. (Holubek, Ružarovský and Delgado Sobrino, 2018).

In this study a robot program is generated within a VE (Virtual Environment) controlled by a Xbox 360 controller. It is discussed the benefits of programming within a virtual environment such as time saved or more intuitive development. The software that is presented, developed in Unity 3D, is really powered, it saves the targets keeping the 6 robot joints values thus obtaining not only the location of the point but also the orientation. When the targets are set the path is generated by interpolation, obtaining a quite accurate movement. While interacting with the virtual robot the code is generated in the V+ programming language and can then be exported to the real robot. Besides, it also features a collision detection system implemented in Unity 3D which changes the colour of the object in the case of the robot end effector is contacting with it. Despite all these assets, the main handicap of this project is the user interface. As mentioned above, the user has to interact with the program by an Xbox controller. To set a target the user has to move the end effector by pressing buttons and increasing or decreasing the X Y and Z values. The same happens to reorientate the end effector. Moreover, because of not using virtual glasses, the user has to take care of the angle of the camera using the controller buttons too. Due to these factors programming in this way can be less intuitive and time-saving than using VR technology. (Michas, Matsas and Vosniakos, 2017).

The next paper describes a software where the user leads the virtual robot to the chosen points with the instantaneous replication of the real robot's movement. The user is equipped with the HTC Vive virtual glasses and controllers, with the latter, the user can move and rotate the controller to reach the desired positions and orientations of the end-effector. This project uses two virtual robots, one is almost translucent and the other one is white. The user can interact with the translucent robot moving it to the desired target. The white virtual robot will follow the translucent robot movements, and, at the same time, the physical robot will replicate the white virtual robot movements. There is a very interesting section that deals with the fact that depending on the accuracy that the operator needs for each task, the movement of the robot will be adapted to this, making the movement more or less sensitive. This is calculated according to the distance from the end-effector to the target. The main weakness from this project is that is not possible to generate a programme from the movements as the programme focuses on the replication of the virtual movement on the real robot. (Su and Young, Kuu Young, Cheng, S. L., Ko, C. H., Young, 2019).

Subsequently, in the following project the team managed to make a software for robot programming using virtual reality. This software uses the inverse kinematics of the manipulators, in this case the 4-DOF Barrett WAM, for generate a code, in ROS, by moving the end effector with the right hand, without the need of a controller, due to the integration of the Leap Motion Controller into the Oculus Rift Headset. Even so, the main problem of the program is that it is not possible to move the different joints of the robot directly, the user can only move the end effector. Furthermore, the application does not have collision detection. (Theofanidis *et al.*, 2017).

The following studio also has a sensor to detect the user's hands (MYO Armband sensor). In this case it detects both hand movements and up to 4 possible gestures. This software allows the user (using VR glasses) to control a virtual robot, making paths, saving targets and determining orientations with hand gestures. It is also possible to generate a program from the simulation and then export it to the real robot to perform the task. However, although the gestures and sensor work for simple movements (like linear movements), the result of characterizing the MYO Armband sensor was not the expected. Moreover, this project has neither the possibility of moving separately the different robot joints nor a collision system detection. (Rodríguez Hoyos, Tumialán Borja and Velasco Peña, 2021).

Afterwards, there is a study of a project that implements an intuitive robot programming using the Microsoft HoloLens. This application generates a virtualization of the robot using augmented reality, with the use of this technology it is possible to move the virtual robot to the desired positions in order to program a trajectory and, in addition, detect the possible collisions. The main problems of this software are that the currently developed software using this tech is exported in KukaRobotLanguage. Furthermore, some of the future work of this project is that it should be necessary to implement more programming options and possibilities for describing flow logic and path planning. Because, with the current application, only a predefined pick-and-place sequence with a free adjustable offset is possible. (Blankemeyer *et al.*, 2018).

# 4. Method (and/or Approach or Implementation)

### 4.1. Essential Functions

### **4.2. User Interface**

### **4.3. Logic Flow**

### 4.4. Program Generator

# 5. Results (and sometimes Discussion)

Different types of projects will have different types of results and will need different approaches to the presentation. In some projects, it can help to include some discussion[[1]](#footnote-4) in this section particularly if there are multiple decision points in an experiment or if the project is staged so that some work must be completed and understood before going on to some final critical steps.

Use sufficient detail to allow the reader to form an opinion on what has been done. Figures, such as graphs and charts, and tables should be used to show both good and bad results. Surprisingly, bad results are often the most interesting. When possible, for the purposes of comparison, include data from the literature or other sources. Where possible, include error bars. A number of subsections should be used to improve the flow of the text.

Often the writer, who is very familiar with the project, finds the results self-explanatory. This is usually not the case for the reader. For this reason each figure, chart, graph and table should have some accompanying explanatory text such as: *Figure 4 shows the relationship between crack growth and applied load*. Try to put the text which refers to the figure or table before the figure or table itself. Only the most relevant material should be presented. Related but less relevant material can be placed in the appendices.

Figures and tables can be numbered in order of appearance in the report, or in the order of appearance the section; e.g., Figure 3.1 and Table 3.1. As indicated previously, the figure number and caption should appear *below* the figure. Table numbers and captions are placed *above* the table.

# 6. Discussion (and sometimes Recommendations)

In the discussion, the writer presents a thorough interpretation of the work by evaluating the assumptions, the results and potential sources of error. Proper use of engineering judgement in the interpretation of the results is critical. The nature of the discussion will depend to a large extent on the type of project; e.g., design, experiment or simulation, that has been undertaken. The specific outcomes and any related recommendations should also be discussed within the broader context of TSE. Use subsections as needed to improve the flow of the text.

One approach is to turn to the introduction for guidance. Consider the problem statement or research question and the justification for studying the problem. Were there specific goals? Were they accomplished? If not, why not? Should some things have been done differently? If so, suggest how.

### 6.1 Technology, Society and the Environment

The results should also be discussed in relation to the relevant disciplinary, social and ethical aspects and issues identified in the introduction. Within the discussion or in *a separate TSE section* address the following questions[[2]](#footnote-5):

1. How have the circumstances and needs of individuals that are affected by the outcome of the project been taken into consideration?
2. How have the relevant targets of the community for economically, socially and ecologically sustainable development been taken into account?
3. How has the solution been assessed in relation to the relevant disciplinary, social and ethical aspects and issues identified in the introduction?

Within the context of the project, provide insight into the role of knowledge and the possibilities and limitations of technology, its role in society and the responsibility of the individual for how it is used. Include the social and economic aspects as well as environmental aspects and occupational health and safety aspects.

### 6.2 Other

The discussion section can also identify any need for future work. Alternatively a separate section can be placed after the conclusions, as below, if there is sufficient material.

# 7. Conclusions (and sometimes Recommendations or Contributions)

The conclusions and in some cases the recommendations or contributions of the project are often presented in a numbered or bulleted list. Each item, perhaps a few sentences long, presents some key result, recommendation or contribution. Indicate what parts of the project were successful and what parts should be improved. The conclusion section will naturally parallel the abstract and often uses expressions such as: has been proposed; has been shown; has been found: and has been recommended.

Some may prefer to include the contributions to TSE as a separate subsection within this section of the thesis.

# 8. Future Work

Many find that it is easier to present the future work after having presented the conclusions and contributions.

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# Appendices

The appendices are standalone[[3]](#footnote-6) titled sections which include essential material that does not fit in the main text; e.g., division of labour; planning documents; development of equations used in the theory; tables of raw data requested by the supervisor; results from multiple finite element analyses; surveys; examples of coding; and initial engineering sketches.

# Appendix 1 Work Breakdown and Time Plan

In this compulsory appendix, the initial work breakdown and time plan (Gantt chart) for the project should be compared with an updated version which shows how the project actually took place. Discuss and reflect upon the differences between the original and the updated versions.

This appendix is related to one of the goals of the program, specifically, that students should be able to respond to challenges that arise during a long project and manage the deadlines accordingly. By reflecting on *critical* changes in both the planning and the direction of the project, an understanding of this aspect of project management can be demonstrated. Identify in *general terms*, those occasions in which the project underwent a substantial change; for instance, explain how and why the goals were reformulated during the project and how the milestones were met when these changes were made.

# Appendix 2 Appropriate Title

Appendix 2, and other appendices, can include other project-relevant material.

1. Guidance for discussion material in Section 4 should be followed if the results and discussion are combined. [↑](#footnote-ref-4)
2. *A numbered or bulleted list* can be used effectively in a thesis. [↑](#footnote-ref-5)
3. As the appendices are standalone documents they often have separate page numbering; e.g., A1.1, and usually separate figure numbering; e.g., Figure A1.1, and separate table numbering; e.g., Table A3.3. Occasionally, it is appropriate to have a separate table of contents and separate references. Use your engineering judgement to determine what is appropriate. [↑](#footnote-ref-6)