SCREW SORTING APPLICATION WITH 6 DoF UR5E ROBOT ARM

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Abstract

As part of the module "Introduction of Collaborative Robot Systems" at the Zittau/Görlitz University of Applied Sciences, a practical robot application using a collaborative robot and the associated human-robot interaction must be examined in a written document. The objective of the document is to design an application for sorting screws in such a way that the motion sequences of the robot are optimized. Safety aspects are to be considered. Subsequently, the concept is to be implemented theoretically and/or practically. The work carried out and the results are to be recorded in a document. In this article, the results of the proof of a student group are presented. Thereby, the article shall give an overview on the possible procedure for the conceptual design of practical robot applications.

Keywords

Human-robot interaction; Collaborative robots; Robot application; Sorting; Screwing; Teaching.

Introduction

Small and medium-sized enterprises (SME) form the basis for a functioning and innovative economy in Germany, but SME are increasingly confronted with social and economic challenges. The social challenges include, for example, demographic change with a declining number of people of working age and the associated shortage of skilled workers. The economic challenges include, for example, steadily increasing international market pressure, rising demand, declining product life cycles and greater diversity of variants. These challenges mean that previously fully automated or manual production processes are becoming increasingly complex. As a rule, fully automated production systems have the characteristic of high productivity but low flexibility, and manual production systems have the characteristic of high flexibility but low productivity. One way of maintaining economic efficiency and counteracting the shortage of skilled workers in industry and the skilled trades is to use hybrid production processes, thus combining the properties of productivity and flexibility. A key technology of future hybrid production environments is the human-robot interaction (HRI) by means of collaborative robots. [1]

The following article presents the conceptual design of an application for sorting screws by means of a collaborative robot, in which humans continue to be part of the process. The goal is the development of a complete sorting routine on the given training platform of the Institute of Process Technology, Process Automation and Measurement (IPM) at the University of

Applied Sciences Zittau/Görlitz with the collaborative robot UR5e of the company Universal Robots. The training platform is shown in Figure 1.
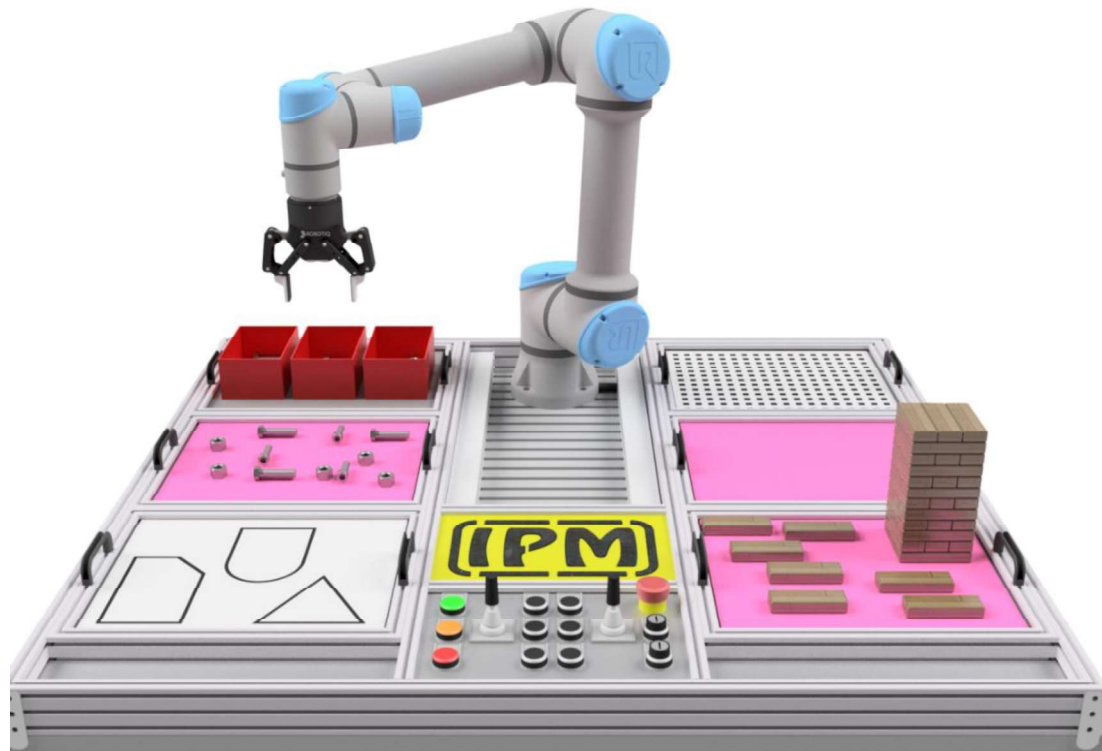
Source: Own

**Fig. 1:** *Training platform for the UR5e collaborative robot from Universal Robots*

The application includes the classification of three different types of screws. The focus of this work is on the presentation of a possible variant of the sorting application, the improvement of the cycle time by optimized motion sequences of the robot as well as a possible integration of safety measures to protect the worker. The identification of the screw type as well as the position in the system by means of methods of image processing and artificial intelligence are not the subject of this work. Rather, the synergy between CAD, CAE, simulation and process management is to be presented.

A CAD model of the training platform serves as a reference for the various coordinate points of the application, which are used as waypoints for the theoretical implementation of the complete routine. The routine is implemented in the simulation software URSim from Universal Robots. URSim is used for offline programming as well as simulation of the created robot program. The results are analyzed and conclusions are derived.

1 Basics

In general, HRI distinguishes between three forms of interaction. For this purpose, it is first necessary to define the possible workspaces in an HRI. Figure 2 shows three possible workspaces:

- Workspace of the worker (WS-W),
- workspace of the robot (WS-R), and
- common workspace for worker and robot (WS-C).
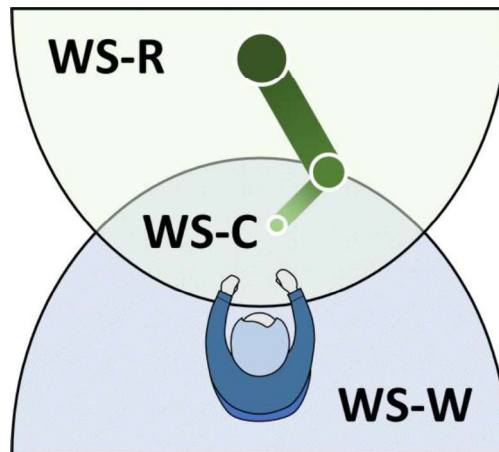
Fig. 2: *Definition of the workspaces in a human-robot interaction*

The possible forms of interaction between worker and robot are shown in Figure 3. In the case of coexistence, the worker and robot work side by side and do not have a common workspace, i.e. the worker and robot work alone in their respective workspaces. The interaction form cooperation is distinguished in two variants. In the first variant (left), the worker and the robot have a common workspace, but they are separated in time, i.e. only one interaction partner is active in the common workspace at any given time. In the second variant (right), the two interaction partners interact simultaneously in the shared workspace, but the interaction partners do not work on the same component at the same time. The last form of interaction is collaboration, in which both interaction partners work on the same component at the same time.
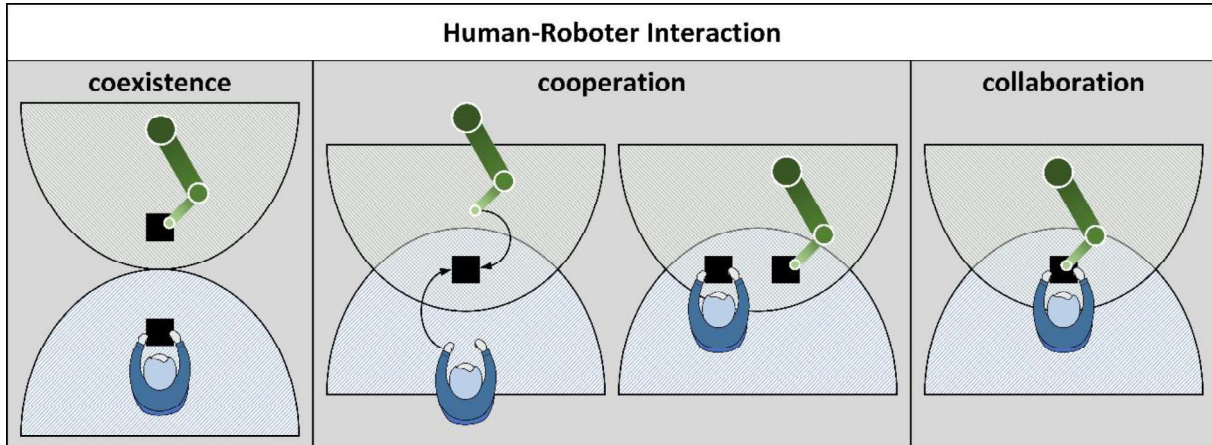
Fig. 3: *Forms of interaction between worker and robot*

There is another special form in which a collaborative robot is used. This special form is full automation, i.e. the robot interacts alone in a cell without the worker being directly involved in the production process. Figure 4 shows full automation as a special form of interaction.
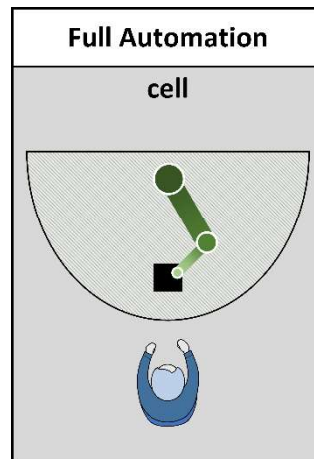
Fig. 4: *Full automation as a special form of human-robot interaction*

Collaboration-capable robots were developed for direct physical interaction between worker and robot. The actual use of collaborative robots is in assembly for 'slow' processes with low payloads and low process forces and serves to support and relieve the worker. The collaborative robot is a sub-component of a robotic system, i.e. for a complete robotic system it is necessary to add an end effector and the necessary peripherals and accessories to the collaborative robot to support the intended application. The end effector is the final link in a robot's kinematic chain. Here, end effectors are subdivided into grippers, tools and measuring or testing equipment.

In addition to selecting a suitable end effector for the respective application, it is also necessary to select a suitable collaborative robot. For the selection of a suitable collaborative robot, various properties and parameters are used, such as degrees of freedom, working space, accuracy, payload and price. For the further considerations, the collaborative robot UR5e from the company Universal Robots is taken.

Universal Robots is a company in charge of developing collaborative robots. This enterprise was developed in Denmark. The most popular product of this company is the six-jointed robot arms. There are only seven different types of six-joined robot arms: UR3, UR3e, UR5, UR5e, UR10, UR10e, and UR16. [3] Figure 5 shows the e-Series collaborative robots from Universal Robots.

Fig. 5: *Models of six-joint robot arms from Universal Robots*

The UR5e is a 6-axis robotic arm produced by Universal robots, with some important aspects like an error ranging from a ±0.1 mm mark, a maximum payload of 5 kg, a reach of 850 mm, and a working temperature range that goes from 0 to 50 °C. [5]

The type and model of the robot is not the only important feature for developing the project, but also choosing the accurate gripper and camera for image processing is of grave importance, that is why in the following paragraphs, the characteristics of the gripper and the camera we choose will be given. Table 1 summarizes the characteristics of the gripper used. Figure 6 shows the gripper used by the company Robotiq.

Tab. 1: *Gripper specifications*

Specifications	2F-140
Stroke (Adjustable)	140 mm
Grip force (Adjustable)	10 to 125 N
From-fit grip payload	2.5 kg
Friction grip payload	2.5 kg
Gripper Mass	1 kg
Position resolution (fingertip)	0.6 mm
Closing Speed	30 to 250 mm/s
Communication Protocol	Modbus RTU (RS-485)
Ingress Protection (IP) rating	IP40

Source: [6]

Source: [6]
Fig. 6: *Gripper 2F-140*

Figure 7 shows the flange camera from the company Robotiq. Table 2 summarizes the characteristics of the used 2D camera.

Source: [7]
Fig. 7: *Wrist Camera from Robotiq*

Tab. 2: *Camera specifications*

| Specifications	Wrist Camera
Sensor and optics	5 MP color sensor, electrically adjustable focus, 70 mm to infinity
Integrated lighting	Two units (white and diffuse LED)
Programmable parameters	- Automatic part programming (user-defined arbitrary shape) - Parametric part programming (circle, ring, square, rectangle) - Edge editing, color validation - 2 convenient camera control modes: basic, advanced - Automatic and manual camera parameters: exposure, focus, illumination LED, white balance
Electric	Direct communication with the UR controller (via USB), and power supply from the controller (24 V).
Weight	160 g
Working temperature	0 – 50 °C
Internal camera image buffer	DRAM memory

Source: [7]

VirtualBox is a powerful x86 and AMD64/Intel64 virtualization product for enterprise as well as home use, it is installed on your existing Intel or AMDbased computers, whether they are running Windows, Mac OS X, Linux, or Oracle Solaris operating systems (OSes). It extends the capabilities of your existing computer so that it can run multiple OSes inside multiple virtual machines at the same time. [8]

This software offers the following advantages:

- Host operating system (host OS).
- Guest operating system (guest OS).
- Virtual machine (VM).

Figure 8 shows the virtual machine interface. There it is possible to select a defined operating system.
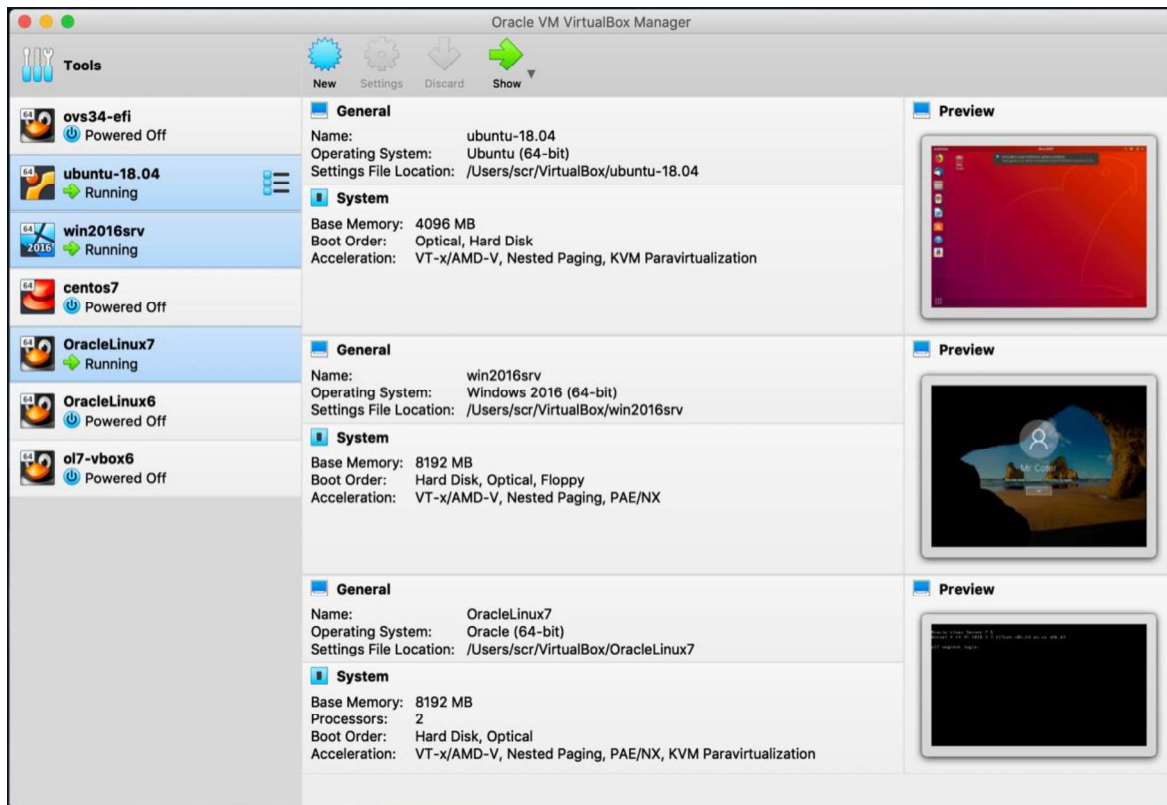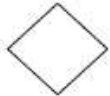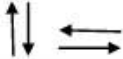
Source: [9]
Fig. 8: *Virtual Box interface*

SolidWorks is computer-aided design software that allows users to create, simulate, publish, and manage 3D models. The technique generally consists of making 2D profile sketches and then using methods to produce the solid shape, be it extrusion, revolution, rounding, chamfering, etc. This allows for the creation of a 3D model (solid or surface), to finally create assemblies with different parts, using geometric relationships. This software was developed by SolidWorks Corp. a subsidiary of Dassault Systèmes, in 1995 in Massachusetts. [10] Figure 9 shows the SolidWorks user interface.
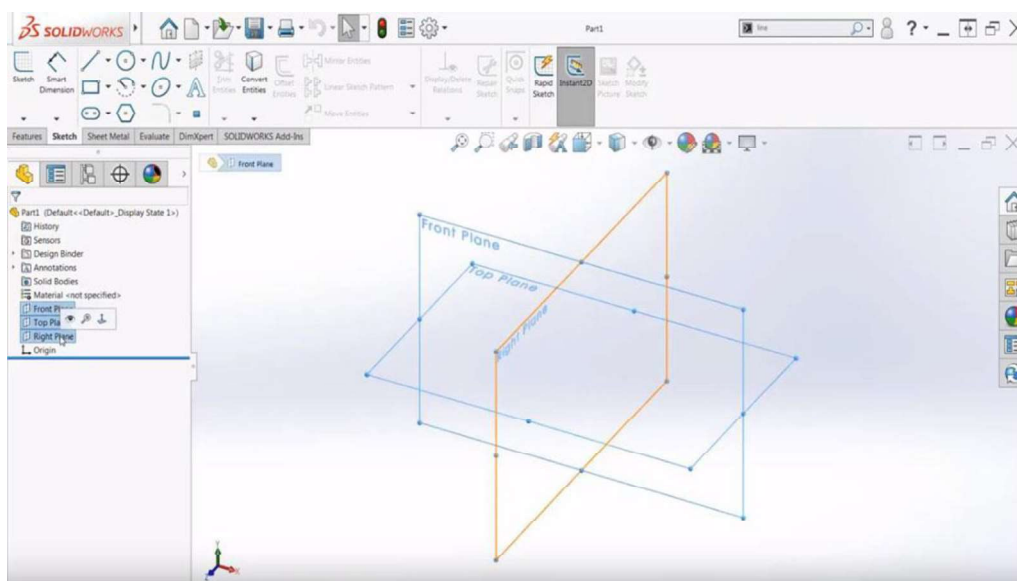
Source: [11]
Fig. 9: *SolidWorks interface*

A flowchart is a diagram that describes a process, system, or computer algorithm. They are widely used in numerous fields to document, study, and plan, improve and communicate often complex processes in clear, easy-to-understand diagrams. Flowcharts employ rectangles, ovals, diamonds, and numerous other shapes to define the type of step, along with connecting arrows that establish the flow and sequence. They can range from simple, hand-drawn diagrams to comprehensive, computer-created diagrams that describe multiple steps and paths. Figure 10 shows and describes some symbols of the flowchart. [12]

Symbol	Name	Function
	Process	Indicates any type of internal operation inside the Processor or Memory
	input/output	Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results
	Decision	Used to ask a question that can be answered in a binary format (Yes/No, True/False)
	Connector	Allows the flowchart to be drawn without intersecting lines or without a reverse flow.
	Predefined Process	Used to invoke a subroutine or an Interrupt program.
	Terminal	Indicates the starting or ending of the program, process, or interrupt program
	Flow Lines	Shows direction of flow.

Source: [13]
Fig. 10: *Flow chart symbols*

As this is a very regulated technique, there are some rules for developing a correct Flow chart, which are the following:

(1)   All boxes of the flowchart are related with arrows.

(2)   Flowchart symbols have an entry point on the top of the symbol with no other entry points. The exit point for all flowchart symbols is on the bottom except for the decision symbol.

(3)   The decision symbol has two exit points; these can be on the sides or the bottom.

(4)   Generally, a flowchart will flow from top to bottom.

(5)   Connectors are used to join breaks in the flowchart.

(6)   All flowcharts end with a terminal or a continuous loop.

(7)   Subroutines and interrupt programs have their own and independent flowcharts.

In order to successfully complete the development of the Flowchart, the software EdrawMax was used.

2   Concept

During the development of the concept, our main purpose is the pick and place application of a variety of screws from a pile to a specific box in concrete numbers; this statement can be oversimplified in broad steps to establish an order of operation from which more specific instructions will take place.

Before the core part of this article, the screws used are described. For this purpose, a bolt and its definitions are shown in Figure 11.
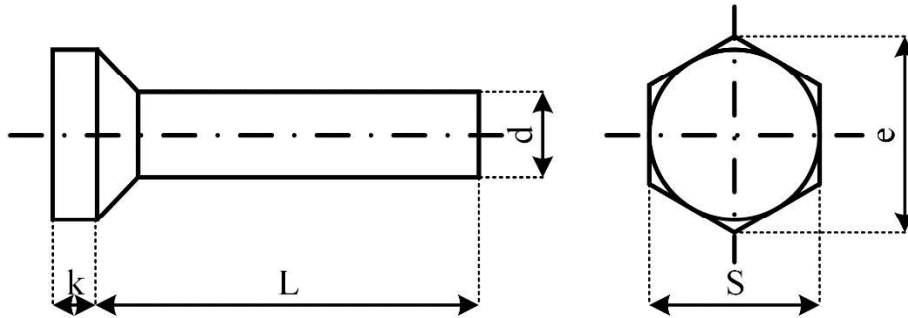
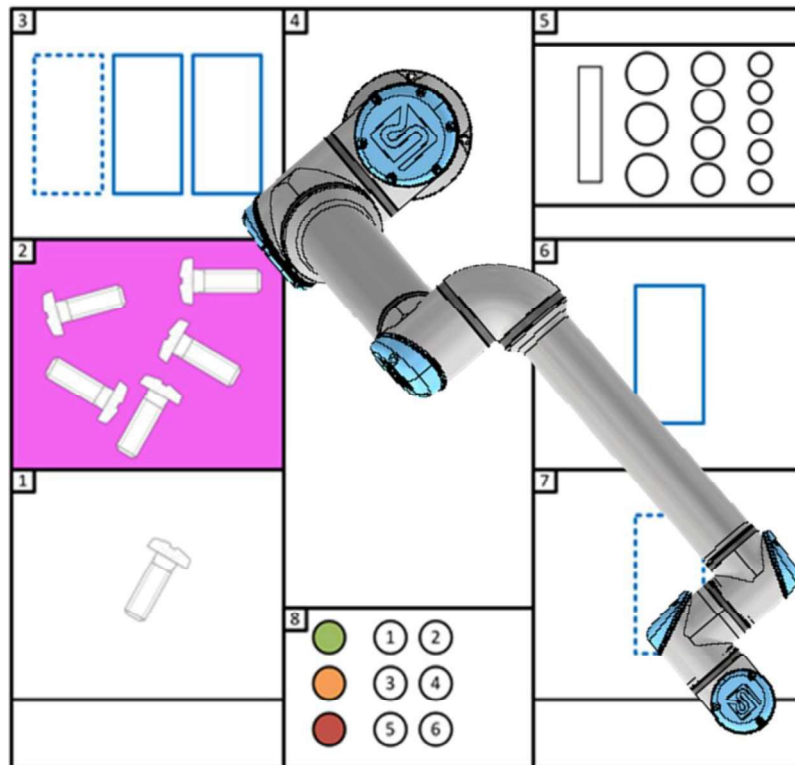*Source: [14]*
Fig. 11: *Screw Schematic*

Table 3 summarizes the screws used and their parameters.

Tab. 3: *Screw Selection*

	M18	**M20**	**M24**
k [mm]	11.5	12.5	15.0
S [mm]	27.0	30.0	36.0
L [mm]	100.0	100.0	100.0
Norm	DIN 933	DIN 933	DIN 933

Source: [14]

The next section will define in multiple steps the timeline of the process that takes place to be able to later program everything in the robot. It will also define some of the considerations that we have laid in and that define the boundaries, limitations, and givens of our project. Figure 12 shows the basic structure of the application. Section 2.1 describes the individual positions and the functional sequence.

Source: Own

Fig. 12: *Training platform arrangement*

## 2.1 Functionality Description

The robot is in the HOME position.

The outside operator loads the varieties of screws in section 2.

The robot goes to section 2.

(1)   The robot selects a screw from the pile.

(2)   The robot places the screw in the correct position in section 5.

(3)   The steps (3), (4), and (5) are repeated until all the racks on section 5 are full.

(4)   The robot takes an empty box from section 3.

(5)   The robot places the box in the correct spot in section 6.

(6)   Steps (7) and (8) are repeated placing a total of 3 boxes in section 6.

(7)   The robot takes the racks from section 5.

(8)   The robot empties the screws on the boxes in section 6.

(9)   The robot leaves the empty racks in section 5.

(10)   The robot takes a full box in section 6.

(11)   The robot leaves a full box in section 7.

(12)   Steps (13) and (14) are repeated for the 3 boxes.

(13)   The robot notifies the operator that the boxes in section 7 are ready to take away.

3   Safety

After examination of the possible failure scenarios and reviewing the theoretical concepts for correct practice, the most accurate action is to introduce the planes of security and define a safety sphere that covers the screw; this plane will be allocated 5 cm after the border of the base. This way, the robotic arm has more space for developing the movements of the routine and at the same time avoiding the cylinder of singularities. This position also circumvents a collision with the operator, while he is passing by or introducing the screws in the first area. In addition, a presence sensor will be installed in front of the first area and another next to the eighth area described below. With these sensors, the speed of the robot will be reduced when the operator introduces his hand to place more screws, this way the robot will be maintained steady when the boxes are full of screws. Figure 13 shows the safety planes of the application with the robot.
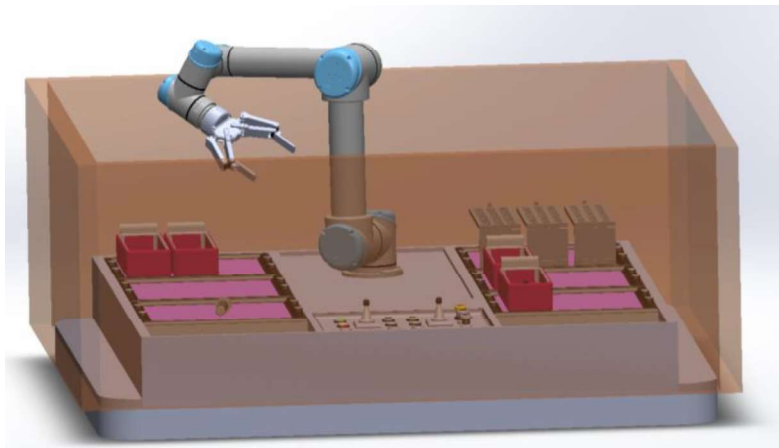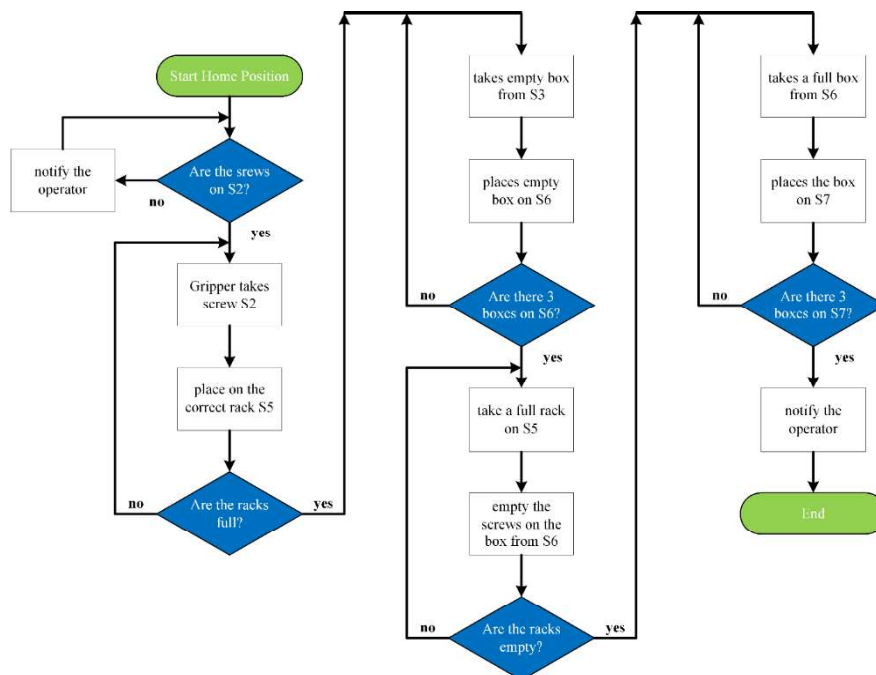

Source: Own
Fig. 13: *Safety Planes*

4   Program Flowchart

Figure 14 shows and describes the flowchart of the application process.

Source: Own
Fig. 14: *Process Flowchart*

5   Summary

For this activity, a 3D simulation in Solid Works was created to simulate a more realistic scenario, in which a square workspace of 1.5 meters was assigned, divided as shown in the instructions. Figure 15 shows the 3D model of the application with the robots.
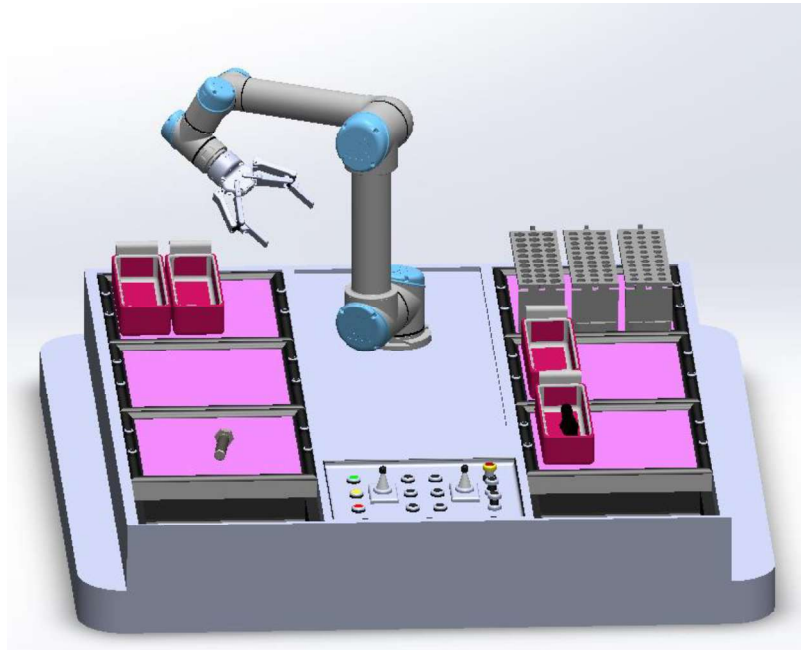
Source: Own
Fig. 15: *3D Simulation of the Process*

Once the 3D simulation was completed, distances from each of the allocations of the pick and place points were taken with the distance tool, as shown in figure 16.
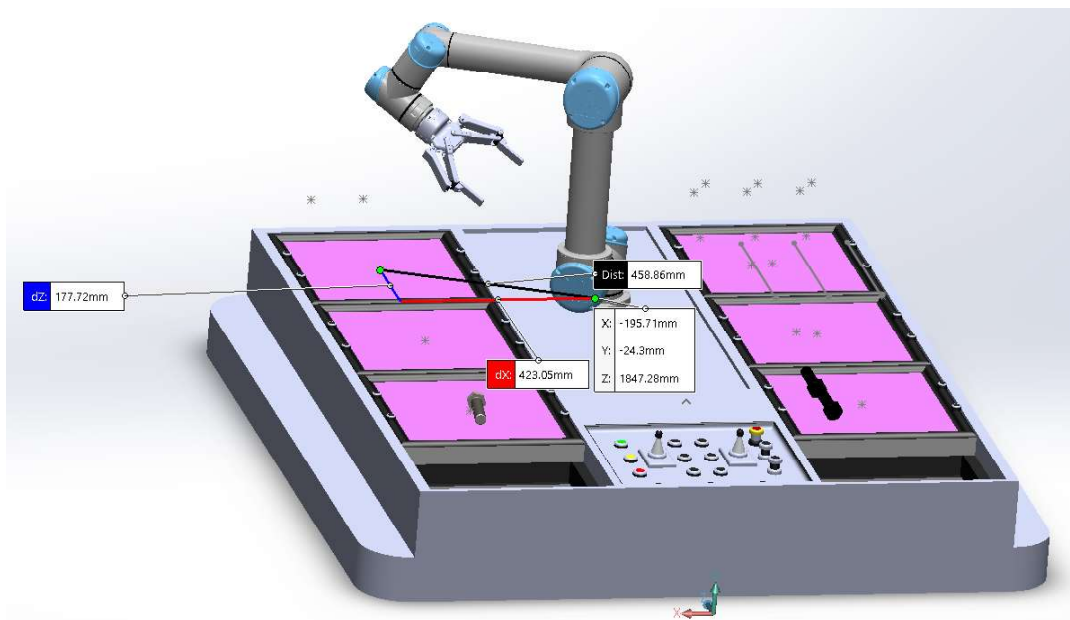
Source: Own
Fig. 16: *Coordinates of the interest points*

To make the process of acquisition of the points easier, a new axis system in the base of the UR5e was created since the coordinates in the software begin at the base of the robot. Figure 17 shows the application with the robots and the new coordinate system.
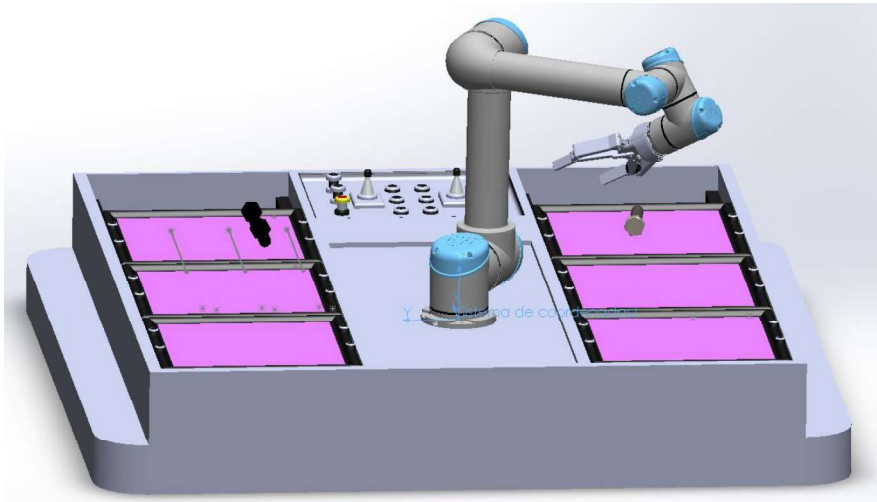
Fig. 17: *New coordinate system*

Once the coordinate points were taken from the model, the distances were introduced in the Universal Robots software to create the program, considering the accurate movements for moving, picking, and placing. While launching the application it was seen that for the completion of one screw, the robot took 6 minutes. For that reason, optimization curves were introduced, and an increase to the speed of the robot. With both of those changes, time was reduced from 6 minutes to 5 minutes and 17 seconds.

Despite the important decrease of time, optimization was further needed in the simulation; that is why a spring system was installed in the racks, this would allow the robot to make a single movement instead of two. With this approach, another minute was saved. Finally, an analysis of the decision points given in the Flowchart was implemented in the program.

An additional step was made to capture a simulation of the program in the Virtual Box. For this purpose, the video conferencing application of Zoom fulfilled that motive. A video of the created program can be found in [15]. Figure 18 shows a QR code that redirects to YouTube. The video on YouTube shows the simulation of the application in the virtual machine.

Fig. 18: *Virtualbox video QR*

Conclusion

Considerations for industry standards must be included for the application to successfully achieve the routing, sorting, and packing application for different types of screws. They will trace the guidelines and rules to be followed for a proper application.

Limitations regarding software components made some concept implementations problematic to implement and place in the virtual machine. Enactment of the described work would have provided more data to analyze weak points of the theoretical application. In terms of this scope, further examination is required for the wired connections to the robot arm and the accurate functionality of the gripper. Nevertheless, the described theoretical application may be used as a basis for an industrial level application with similar proposed parameters.

One of the main objectives was the further optimization of the process even when it was already constrained by programming factors. For example, the system of springs installed in the rack helps the operator to program the first movement to place the screws in the box and the spring itself returns the rack to its place, this way movements and times are reduced.

Additionally, research for different types of grippers was made to obtain information about the ones available in the market which would fit best for the application. Filters were applied to the selection depending on their dimensions, costs, and functionalities. The chosen gripper was the 2F-140 because of its cost compared to the other options, its good traction and its shape that allows for thrift of movements to avoid changing the directions for picking and placing. On the other hand, the selection of the camera depended on the selection of the gripper. This was due to a lack of information regarding a handful of deep learning cameras that would be suited for the application. The only way for a camera to be integrated into the arm of the robot itself was only if a combination of both was selected.

The functionality of the camera and its image processing capabilities were indirectly given in the code, but a written description of it was not added. A practical approach would have made the configuration introduced to the code in the Universal Robots program much clearer by using the camera as an input. Given the scope and approach of this investigation, it was left implicitly.

Since the theoretical basis of the enactment of the 6DoF robot arm for the screw sorting application has enough descriptions and meets the considered optimization objectives, it can be stated that the routine is complete, and it now can be used as the basis in an industrial sorting application.

Acknowledgments

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APLIKACE TŘÍDĚNÍ ŠROUBŮ S ROBOTICKÝM RAMENEM UR5E SE 6 STUPNI VOLNOSTI

V rámci modulu „Úvod do kolaborativních robotických systémů" na Vysoké škole aplikovaných věd v Žitavě/Görlitz je třeba písemně zpracovat praktickou aplikaci robota s využitím kolaborativního robota a související interakci člověka s robotem. Cílem dokumentu je navrhnout aplikaci pro třídění šroubů tak, aby byly optimalizovány pohybové sekvence robota. Je třeba zohlednit bezpečnostní aspekty. Následně je třeba tento koncept teoreticky a/nebo prakticky realizovat. Provedené práce i výsledky se zaznamenávají do dokumentu. V tomto článku jsou uvedeny výsledky důkazu skupiny studentů. Dokument by měl poskytnout přehled možného postupu při koncepčním návrhu praktických robotických aplikací.

SCHRAUBENSORTIERAPPLIKATION MIT 6 FREIHEITSGRADEN UR5E-ROBOTERARM

Im Rahmen des Moduls „Introduction of Collaborative Robot Systems" an der Hochschule Zittau/Görlitz ist es als Prüfungsleistung erforderlich eine praxisnahe Roboteranwendung unter Einsatz eines kollaborationsfähigen Roboters und die dazugehörige Mensch-Roboter-Interaktion in einem schriftlichen Beleg zu betrachten. Die Zielstellung des Beleges ist es, eine Anwendung zum Sortieren von Schrauben so zu konzeptionieren, dass die Bewegungsabläufe des Roboters optimiert sind. Dabei sollen sicherheitstechnische Aspekte berücksichtig werden. Anschließend soll das Konzept theoretisch und/oder praktisch umgesetzt werden. Die durchgeführten Arbeiten sowie die Ergebnisse sind in einem Beleg festzuhalten. In diesem Beitrag werden die Ergebnisse des Beweises einer studentischen Gruppe vorgestellt. Dabei soll der Beleg einen Überblick zum möglichen Vorgehen zur Konzeptionierung von praxisnahen Roboteranwendungen geben.

APLIKACJA SORTOWANIA ŚRUB Z RAMIENIEM ROBOTYCZNYM UR5E O 6 STOPNIACH SWOBODY

Celem niniejszego artykułu jest przedstawienie rozwoju pełnej procedury sortowania na platformie Universal Robots dla modelu UR5e, w której sortowane są trzy różne typy śrub, które są przyporządkowane do różnych, wcześniej ustalonych etapów. Model CAD jest udostępniony jako odniesienie do różnych punktów współrzędnych zastosowania, które mają być użyte jako punkty orientacyjne w symulacji Virtual Box w celu zaprogramowania pełnej procedury a następnie wyciągnięcia wniosków na podstawie analizy wyników.