Automatic Quality Control Workplace Design

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Abstract

This article deals with automation of dimensional control on Coordinate Measuring Machine using a collaborative robot. Thanks to the dimensional control automation, it is possible to save staff capacity as well as to increase the repeatability and productivity of component measurement in series production. Within the design and implementation of the workplace, the subject of inspection was chosen. Necessary equipment of workplace and variants of workplace layout were designed for the inspected part. The part of workplace realization was also to create a robot program to fully automate the process, including product placement and placement after component inspection, depending on the measurement result. The result of the project was an automated inspection of components, which could be implemented with minimal modifications to the real manufacturing system.

Keywords: Quality Control Automation, Collaborative Robot, Coordinate Measuring Machines, Collaborative Workplace

1. Introduction

The main target of this article is to design and implement an automated workstation of dimensional control on a CMM using a collaborative robot. The first part of the article briefly describes basics of collaborative robotics and the collaborative robot YuMi. Furthermore, the article deals with the design of the workplace based on the project input parameters. Then the simplified verification of the chosen variant using the RobotStudio (software for ABB robots programing) is described. Collaborative robot is a suitable solution for manipulation and assembly of small parts. Main advantages are high positioning repeatability, small dimensions, ability to work with humans and elimination of safety fencing features. Control measuring machines (CMM) are optimal solution for automated component control with rapid analysis and measurement results evaluation. The last part of the article introduces the process of control program creation for an automated control workplace.

1.1 Collaborative robotics

Robots from the past are perceived as man-made devices that can easily injure a person or even cause death due to his inattention. A possible solution was to eliminate the human action out of the robot workspace, to prevent injury. The most common solution was the safety fencing of the robotic workplace. However, for the full and productive engagement of robots in some assembly areas, was sometimes necessary to allow human intervention in the robot's workspace. This was one of reasons for the establishment of collaborative robotics, which allows and defines the sharing of a common space for a human and robot. [1], [2]

The exact purpose of collaborative robots is to produce or create something by common activities (cooperation) with humans. It is important to emphasize that collaboration takes place in a collaborative workspace between a robot and a person in collaboration. Often, people think that any non-fencing robot is collaborative and designed to work with people. If additional safety features complying with ISO 10218 safety guidelines are used, then the robot can be called collaborative, but it is not a robot for collaboration with humans. There are several types of collaborative robots, but so far only one type is designed to work with humans without additional safety features. [1], [2], [3]

1.2 Collaborative robots' safety

The safety requirements of collaborative robots' industrial systems and the working environment are specified in ISO 10218-1 and ISO 10218-2 (Industrial robot safety requirements). The standard describes a total of four modes of space sharing between a robot and a human. A novelty is the technical specification ISO/TS 15066, which complements the requirements and instructions described in ISO 10218-1, 2 for the implementation of collaborative robots in order to control human injury risks. For the first time, ISO/TS 15066 lists the maximum limits of allowed force and speed of force limited collaborative robots. The document defines force and pressure limits on 29 areas located on human body. It is based on the so-called pain study, providing guidance, how to determine the maximum robot speed, that the final effector does not exceed the limit value and helps reduce and evaluate risks. [1], [4]

1.2.1 Types of collaboration

In the available ISO 10218 standard are described four types of human-robot workspace sharing (see Fig. 1.). "Safety-rated monitored stop" only offers the coexistence of a human and a robot. The robot is fenced and when a

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human enters the defined area, the robot stops all movement. The second type, “Hand guiding” is used to manually guide the robot by hand along trajectory which is immediately memorized. In case of using the “Speed and separation monitoring” mode, the robot is no longer fenced and the work area is divided into safety zones. The zones are monitored by laser scanners or a visual system, which after the entrance of human immediately slows the robot down and then stops it completely. Robots which work most often in the “Power and force limiting” mode are called collaborative. The robot is programmed to record motor overload using sensors and stop immediately after the exceeding allowed value. [1], [3], [5]

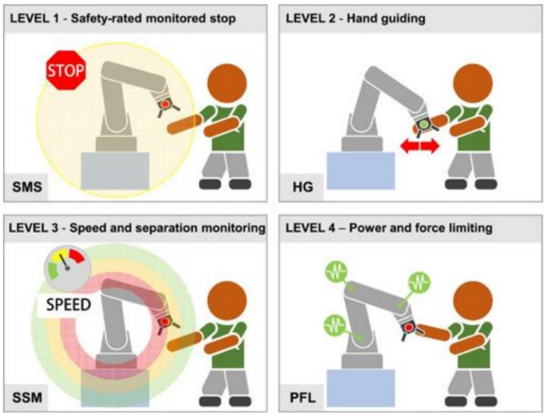

Fig. 1. *Types of collaboration [6]*

1.3 ABB YuMi

YuMi (see Fig. 2.) is one of the most renowned collaborative robots in the world. YuMi is a lightweight robot (38 kg), which is equipped with two seven-axis robotic arms. It can work as two independent robots, but more often relatively easy synchronization of both robotic arms is used. An interesting feature of this robot is the control unit, which is placed directly into the robot's body, or the fact, that the robot is assembled directly on the workbench board. Moving parts of the robot (robotic arms) are rounded and covered with a protective rubber to increase safety. In addition to the soft surface, the safety is provided by sensitive motor sensors (1.2.1). Yu-Mi is in basic version equipped with an end-to-end effector on each shoulder in the form of parallel fingers, which also meet all safety criteria. To enhance the functions, robot can be equipped with an integrated camera or suction cups with air inlet. The target application of the robot is primarily a small assembly, most often assembly of small electronics, due to the low carrying capacity (one arm) 0.5 kg. However, the low load capacity is compensated with precision and relatively fast arm moving speed (1.5 $m*s^{-1}$) Specifically, the position repeatability indicated by the producer is ± 0,02 mm. [1], [7]

Table 1. *Technical specifications of the robot YuMi [1], [7]*

YUMI (IRB 14000)				
Lifting capacity [kg]	Max. reach [mm]	Position repeatability [mm]	Weight of robot [kg]	Degree of freedom number
0,5 (2x)	559	± 0,02 mm	38	7 (2×)

Fig. 2. *Collaborative robot YUMI [1]*

1.4 Zeiss Duramax

Zeiss Duramax (see Fig. 3.) is a coordinate measuring machine suitable for workshop measurements. The advantage of this machine is the space-saving design with integrated system for passive vibration damping. The machine does not require compressed air supply and thanks to temperature stability allows to measure components in the range from + 18ºC to + 30ºC. In addition to temperature stability, Duramax is also dust and moisture resistant with IP54 protection and therefore can be used directly outside the metrology laboratory. [8]

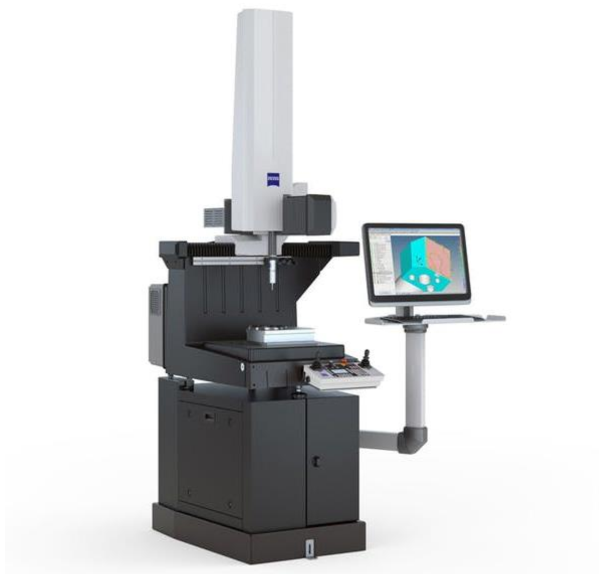

Fig. 3. *CMM Duramax*

2. Control workplace design

Based on the input parameters of the project only the use of the collaborative robot ABB YuMi and the CMM Zeiss Duramax was determined in beginning (see Fig. 5.). The result of the project had to be a fully automated workplace of dimensional control of components.

During the complex design of entire workplace was firstly decided the orientation of the collaborative robot YuMi relative to Duramax. The position was chosen that the robot was facing Duramax, because both machines had to be accessible from side.

2.1 Concept of quality control

At first, the obvious flow of the part and controlled object was determined. For component transport was decided that the components would be supplied to the workplace exactly aligned in the boxes from which the robot would take them. Firstly, the robot places the component in the proposed Duramax fixture and initiates the control measurement with the signal. Secondly YuMi removes the part and places it into the corresponding-correct or non-corresponding-scrap component box, according to the CMM measurement result. As the final part was selected a drink cup (see Fig. 4.). The reason for the selection was suitable shape, size and weight.

Fig. 4. *Selected component with engraved CTU emblem*

2.2 Designed workplace variations

The YuMi robot was initially attached to an easy-to-carry steel construction table which had unfortunately not enough space on worktop. Therefore, it was not possible to deploy the necessary parts and accessories to place the workplace (boxes for controled parts) only on this table. One option (see Fig. 5.) was an additional table between the robot and Duramax, which would be firmly attached to the original robot worktable. Another variant calculated with the free-standing tables alongside both sides of the robot. This option was unsuitable due to the possible displacement of the auxiliary tables. The robot's repeatability and accuracy is high and therefore even a smaller table offset could damage an automatic measurement cycle.

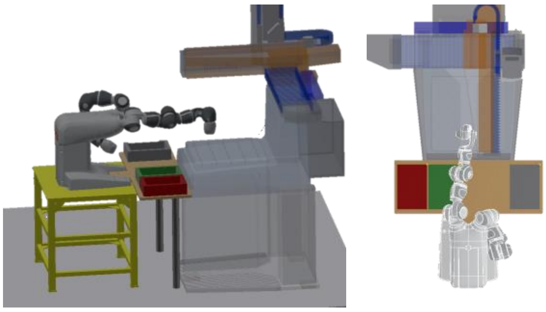

Fig. 5. *First design of auxiliary table*

The last and most suitable option (see Fig. 6.) was the creation of a special table with a cavity in the worktop copying the shape of the robot´s contour. The new hollow board was firmly attached to the original robot table. The original table was also covered on all sides with boards and locking doors from both sides. The worktop size has been designed for convenient placement of control component in a fixture located on the Duramax worktop. At the same time, the length of the table top could not be too short, because boxes with components had to be placed in front of the robot base (closer to Duramax) to be easily accessible for the robot. The advantage of this option was also the ability to directly fix the top of the table and top of Duramax worktop, removing the degree of freedom in one direction.

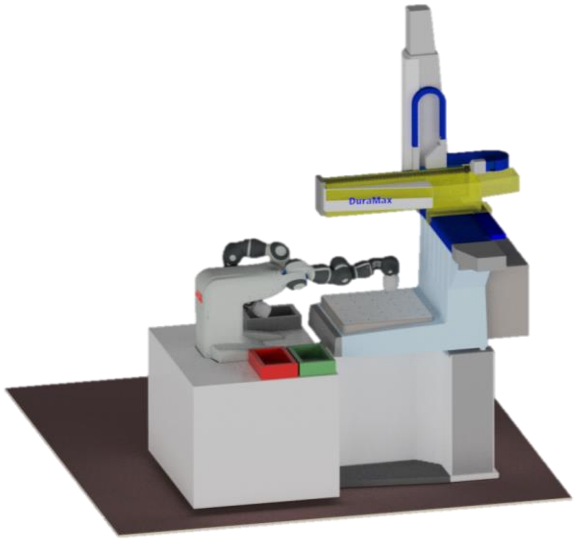

Fig. 6. *Final worktable option*

Representations of the final workplace were designed together with the design of the worktable. Because of worktop and Duramax, the position of most of workplace was predefined, and basically only worry was the placement of auxiliary table. The main selection parameter was the appropriate position of the robot in order to reach the worktop of the CMM while not obstructing the measurement performance. Other parameters of the choice were also the final appearance and minimization of the workplace area. (see Fig. 7.).

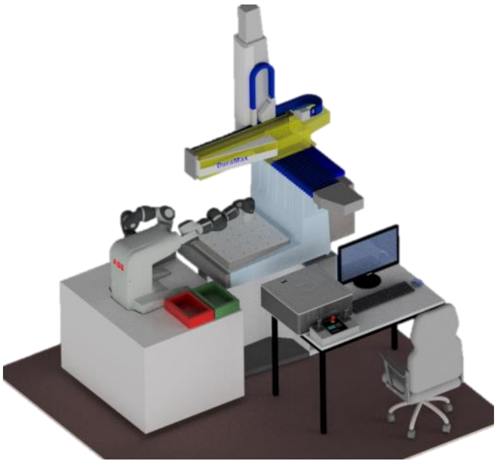

Fig. 7. *Final workplace design option*

2.3 Additional workplace equipment

In addition to the table was necessary to design the appearance of the auxiliary workplace (see Fig. 7.) for Duramax components. The requirement was to put the necessary computer assembly along with the Duramax driver on the table. The table had to look similar to the main table for the robot due to its representative appearance and at the same time dimensions of the table had to be minimized order not to unnecessarily increase the required area of the workplace.

Gray input boxes, red and green output boxes were purchased. Green boxes were designed for correct components, while red crates were designed for scraps. In addition, a drink cup-shaped conical cavity fixture jig was attached to the Duramax worktop using a screw. Also, were designed jigs for transferring the cups to the original position, determining the positioning and orientation of the cups inside boxes, accurating determining the position of the boxes on the worktop, or a parallel-end effector (see Fig. 8.) directly for manipulation with cups. Most of the mentioned components were manufactured using 3D printing on the Stratasys printer. Most of the components had several design variations because first printed variations were often not ideal. For the illustration, the first design of the end-effector of the robot (gripper) and the preparation of the 3D printing of the jigs placed into boxes are presented (see Fig. 8., Fig. 9.).

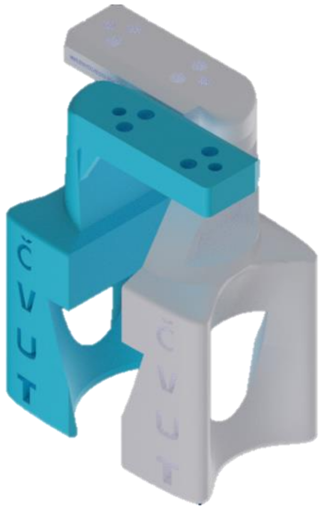

Fig. 8. *End-effector (gripper) design*

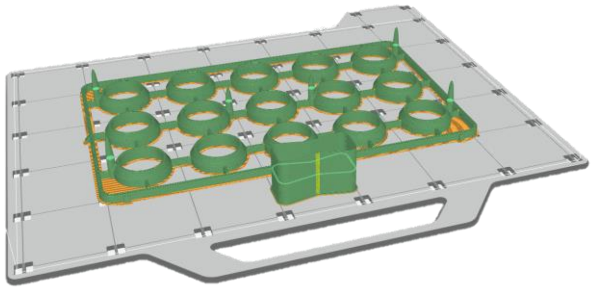

Fig. 9. *3D printing preparation illustration*

2.4 Verification and program creation

The aim of the project was not only to design the workplace but also implement it. Before purchasing the equipment, it was necessary to verify the designed workplace. It meant to test all proposed robot positions and their availability in real conditions.

For the purpose of verification of working positions was used RobotStudio SW (see Fig. 10.) made by ABB company for ABB robots programming. The advantage of RobotStudio is a complete and up-to-date robot control system together with the robot kinematics. Therefore, if the robot in the RobotStudio software can reach all necessary positions, it should not be a problem to implement the workplace. However, for verification purposes, entire program was not created, but only certain parts of the trajectory, which allowed to test the robot configurations at certain removal positions.

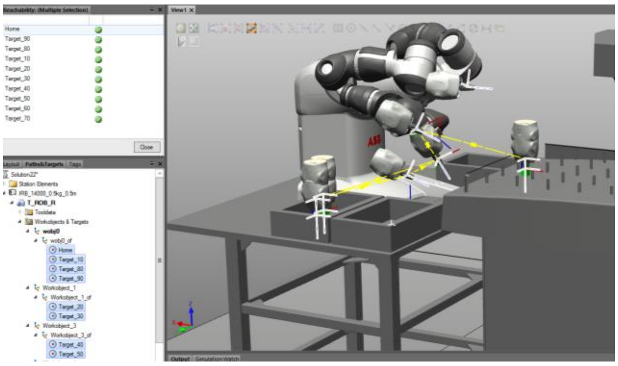

Fig. 10. Verification of taking positions and trajectories

Results of verification were optimistic. At first, we thought it would be necessary to underlay the original table because the worktop was well below the Duramax worktop. We assumed that the robot would not be able to push the cup at this height and distance with linear motion down into the jig. However, the verification showed that this position allows the robot to slide in the cup and implementation of the workplace could proceed.

3. Robot program creation

The creation of the program was probably the most difficult part of the project. Programming was performed by a combination of online programming on the FlexPendant unit (see Fig. 11.) and offline programming in RobotStudio SW, using the possibility of collaboration. By relocating the individual robotic arms, the positions in the space were stored and interlaced the resulting robot arm trajectories. RobotStudio SW was used for rewriting values, parameter changes, listing of program functions, camera settings and other options.

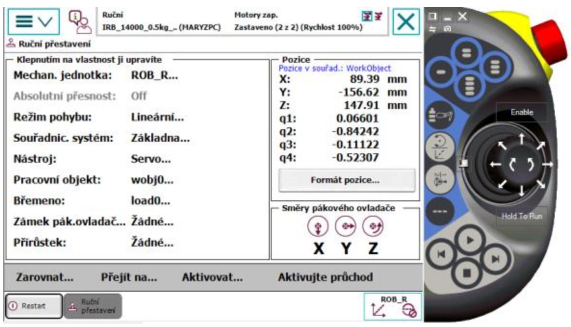

Fig. 11. Virtual FlexPendant

3.1 Simplified program scheme

The basic idea was to create a total of 90 routines that were then linked using logical program functions. The first 15 (contents of one crate) routine was for the right robotic arm that placed the cups sequentially in the Duramax jig. The next 30 routines were for the arm, which, based on the measurement and signal evaluation from Duramax, placed the cup in green box in case of approval or in the red box in case of non-approval. At this point, the robot would begin to measure a new input crate, but due to the planned showcase, we created additional 30 left arm and 15 right arm routine in order to rearrange the cups back into input box after control.

```
MODULE Module1
    CONST robtarget Target_20:=[[15,15,40],[0,1,0,0],[-1,-3,-2,4],[101.964249575,9E+09,9E+09,9
    CONST robtarget Target_10:=[[15,15,0],[0,1,0,0],[-1,-3,-2,4],[101.964249575,9E+09,9E+09,9E
    CONST robtarget Target_30:=[[89.387946423,156.622117957,147.913470217],[0.066010726,0.8424
        VAR syncident sync1;
        VAR syncident sync3;
        VAR syncident sync4;
        VAR syncident sync2;
        VAR tasks waitsynctasklist_1;
    PROC Path_10()

    ENDPROC
    PROC PathLeva()
        MoveJ Target_20, v400, fine, tool0\WObj:=WO_ZelKostka;
        SetDO doFingers_L,1;
    WaitSyncTask sync1,waitsynctasklist_1;
        WaitDI diFingers_L,1;
        MoveL Target_10, v400, fine, tool0\WObj:=WO_ZelKostka;
        SetDO doAttach_L,1;
        SetDO doFingers_L,0;
        WaitDI diAttach_L,1;
    WaitSyncTask sync2,waitsynctasklist_1;
        MoveL Target_20,v400,fine,Servo\WObj:=WO_ZelKostka;
```

Fig. 12. Program routine illustration

All these routines and the entire robot program were interconnected using logic program functions in order to cope with all the anticipated process anomalies. Both robotic arms were synchronized using the corresponding program functions, such as "WaitSyncTask". The robot was able to deal with the missing cup and immediately proceeded to the next position in the box. The robot also missed empty positions in the box during rearranging of cups, because the robot counted suitable and inappropriate pieces during the measurement and knew what positions occupied in the carrier. In the case of a missing cup at the end of the cycle, the robot checked the replaced area with the camera and included the found cups into empty spaces in the carrier. Next task was to with the exact positioning of the cup in the Duramax jig, therefore each cup was pushed with a defined force through the end effector into the jig.

The synchronization robot-CMM was provided by digital signals. After placing the cup, the robot sent a signal to start the measurement. This was followed by measuring the component and evaluating the measurement. By returning the measuring head to its starting position, Duramax sent a signal to the robot. To avoid further measurement, the robot has switched off the safety signal required to start a new component measurement. Based on the measurement result, the robot then placed the part in the appropriate box. For higher safety, during the movement of the robot in workplace of CMM was added additional safety function. This function was checking the start position of the measuring head, in case of non-coincident position, the robot stopped immediately and called the operator. This situation could only occur if the signal was sent incorrectly during control or employee interfered the measurement process. So, two-stage collision protection for the robot arm and the measuring head was provided.

The resulting debug task had nearly 6,000 program lines. During the programming were encountered several minor problems, but all problems were gradually eliminated, and the program was completely debugged. The program would be applicable to a real manufacturing system if minimal changes are made.

4. Conclusion

The activities described in this article resulted in the design and implementation of the automatic quality control

workplace. The motivation for the existence of such a workplace is based on the current needs of the industry, where not-enough qualified employees are particularly noticeable, especially in larger companies.
Two main facilities were connected within the workplace, namely collaborative robot: ABB YuMi and coordinate measuring machine (CMM): Zeiss Duramax.
Based on input parameters, several designs of the fully automated quality control workplace using collaborative robot were performed. In addition, a number of necessary fixtures and equipment needed for the workplace were designed and manufactured using 3D printing. The functionality of the final variation of the workplace in was verified the RobotStudio software. Then the robot program was created and debugged using a combination of online and offline programming.
Thanks to the physical implementation of the workplace and the creation of a control program for the measurement of the specified component, the fully automatic operation of the dimensional control at this workplace was achieved. From the point of view of implementation of created designs, or of the workplace itself, only change of the points for the robot's movement would be necessary to implement the workplace into real production system, but the core of the program and the workplace remains the same.

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