Modeling manufacturing for collaborative and industrial robotics

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***Abstract*— Collaborative robotics is a novel and important topic in education and in the manufacturing area, because it is about the mutual work of human and machine. This technology doesn't have generally accepted standards yet that makes it an interesting topic in education. The paper presents the application of collaborative robotics in a sample manufacturing process involving circuit design, end of line testing, in-circuit testing, visual inspection and image processing for position recognition.**

Keywords—collaborative robotics, practical education, industry 4.0, smart manufacturing

I. INTRODUCTION

Technical and technological advances involve new risks and new requirements [1]–[3], thus safety requirements of industrial robots in the classic sense are changing. In today's factories, robots operate physically separate from humans in a space enclosed by fences and sensors. Looking to the future, the goal is to change this situation so that humans and the robot can work together in one space, sharing the work, relieving workers of monotonous work and supporting precision operations. This innovative technology brings economic benefits and demonstrates significant performance gains also. However, it is important to carefully plan workflows and establish proper human-machine communication [4], [5].

The automation of certain work phases has been simplified due to advanced technology, but there remain jobs where human activities cannot be performed by robots on their own. In such cases, the use of collaborative robots can be of great help [6]–[8]. Collaborative robots have been developed to be able to perform a specific task in a common space with humans at the same time. Human operator controls and monitors production processes while the robot takes on the heavy work. The responsive, lightweight collaborative robot is able to work hand-in-hand with people, without the need for a fence, applying innovative security solutions.

The idea for the collaborative robot was born in 1995 as a result of a research project sponsored by the General Motors Foundation. The goal was to develop robotic applications that work directly with people. Nowadays collaborative robots are becoming more widespread, yet few can sum up how they differ from traditional industrial robots.

II. PROBLEM DESCRIPTION

A. Man-machine teamwork

We see classical industrial robots as power plants that perform their tasks according to a predetermined program, ignoring other work around them: humans, operators. To prevent accidents and hazardous situations, robots are separated from the production area by cages and barriers.

Collaborative robots, on the other hand, are not "born" to replace humans, but are meant to support human activities. Instead of being surrounded by protective fences, they are located directly in the human environment, helping them with tasks that cannot be 100% automated, but providing machine assistance to operators to solve them. They can be used, for example, for conveying materials, lifting heavy workpieces or clamping.

B. Taking on dangerous tasks

Collaborative robots, instead of humans, can perform riskier work tasks, such as moving sharp, pointed or hot workpieces, or assembly in tight spaces. This reduces accidents and allows operators to focus on tasks that require human intervention and capabilities.

C. Flexible and secure

These robots are fully developed for reliable and secure interaction with humans. Thanks to sensitive sensors, they can be controlled with gentle touches to avoid dangerous situations. They do not require the use of fences and grilles.

D. Clever and teachable

Teaching collaborative robots is very simple: unlike traditional industrial robots, which require advanced programming skills, some collaborative types can learn independently. For example, the robot arm is able to re-write the path the operator has led him through. Other types are taught through a graphical programming interface. It follows that the reprogramming of collaborative robots is much simpler than that of their classic counterparts.

E. Applicable anywhere

Not only are they easy to teach they are also moved and installed easily! They are easy to move and apply to other production tasks. Most collaborative robots can be assembled and fixed on any surface, either horizontally, vertically or even on the ceiling. And their weight is usually so low that it is not a challenge to relocate them.

F. Standards for collaborative robotics

The legal background for collaborative robots is not yet clear in terms of safety at work. The standards available on this subject are guiding, but many situations arise during their practical application which are not answered. The main reason for this is that collaborative robot technology is extremely innovative and has a short history of application.

Currently known and applied standards are:

- MSZ EN ISO 10218-1:2011
- MSZ EN ISO 10218-2:2011
- MSZ EN ISO 12100:2011
- MSZ EN ISO 13850:2016

- MSZ EN ISO 13855:2010
- ISO/TS 15066

There are three main concepts that can be distinguished for the definition of the man-machine common workspace as it can be seen in Fig. 1.

Fig. 1: Coexistence, cooperation, collaboration [9]

III. EXPERIMENTAL SETUP

The purpose of the experimental setup is to demonstrate the advantages and disadvantages of industrial and collaborative robots in an educational environment. Accordingly, the laboratory environment is also a training room, which, besides the production cell, contains the PCs needed to run and train the simulation environments (see Fig. 2). The experimental setup shall meet the following requirements:

- tight space
- quiet environment
- clean workflow
- easy to walk around
- visibility of processes

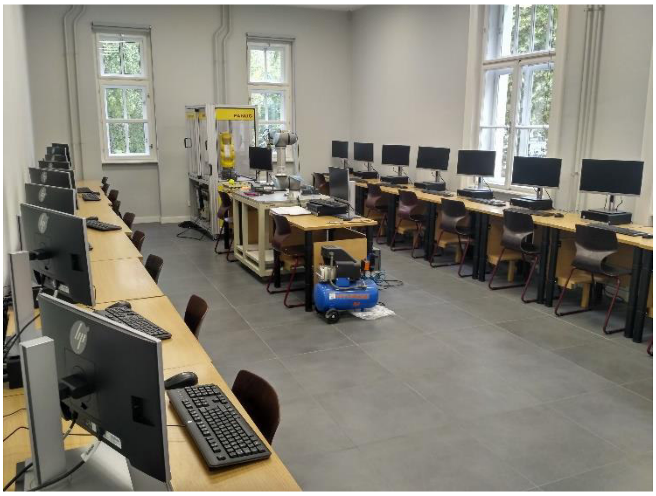

Fig. 2: Robotics laboratory

The industrial robot is represented by a Fanuc education cell (see Fig. 3), Which allows the presentation of the following topics:

- Collision Detection
- DCS Position/ Speed Check
- DCS Safe I/O Connect
- Motion Optimisation
- Constant Path
- Program Shift
- Multi Tasking
- FTP Interface
- Condition Monitor
- High Speed Skip
- Image processing (iRVision)

Fig. 3: Fanuc education cell

The collaborative robot is represented by a UR5e (see Fig. 4), a 5 kg e-series robotic arm from Universal Robots. This robotic arm has a built-in force and torque sensor that ensures the collaborative requirements. The figure also shows that unlike the Fanuc cell, the UR5e robot is not surrounded by a fence in a collaborative workspace. Although the robot itself is collaborative, designing the working environment like gripper, sharp corners, etc. they include non-collaborative elements, the illustration of which is important in educating this topic.

Fig. 4: Universal Robots education cell

When designing the sample process, the basic goal was to present as many important elements of robotic manufacturing as possible. Therefore, we chose testing and assembly of a printed circuit board (PCB) (see Fig. 5). The manufacturing process has four main tasks:

- in-circuit testing
- iRVision positioning
- assembly
- visual inspection

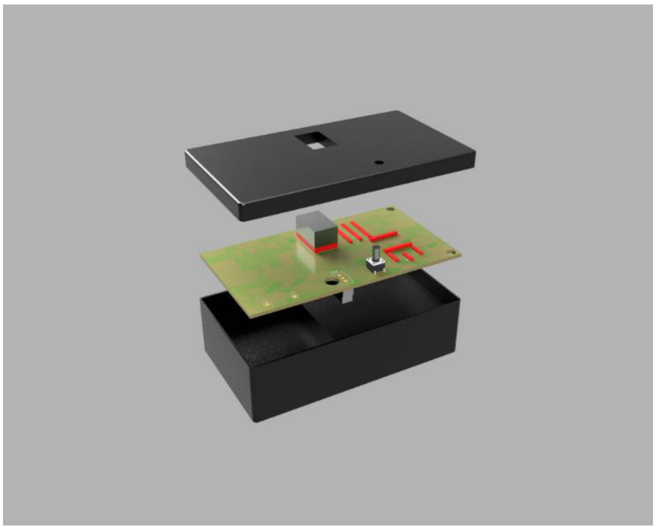

Fig. 5: Assembly of the product

The PCB itself performs a simple task: after pushing a button a random number is displayed on a seven-segment display (see Fig. 6). The role of the circuit in the process is the demonstration of real manufacturing processes thus it has to be compatible with in-circuit testing. Accordingly, there are test points on the circuit where the probes can perform automated testing.

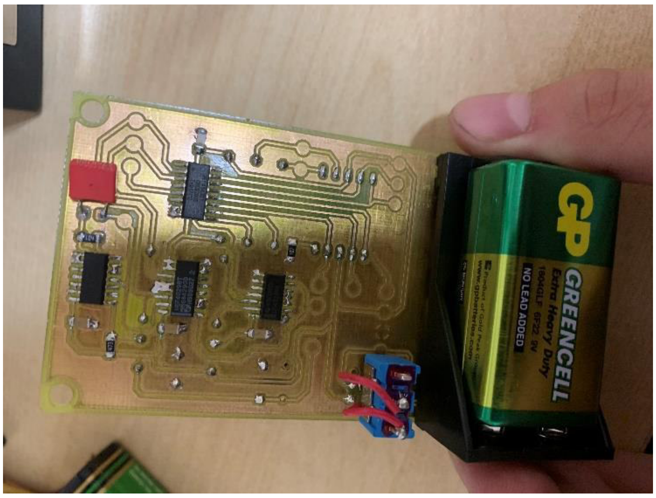

Fig. 6: PCB of the product

The in-circuit testing of this PCB is performed using the bed of nails tester shown in Fig. 7. The most important element of the system is the fixture, which is used for clamping the circuit to be tested. This ensures the contact between the circuit test points and the system. The mechanical strength of the clamp is ensured by a metal frame. The bed of nails is usually placed in an epoxy resin matrix form.

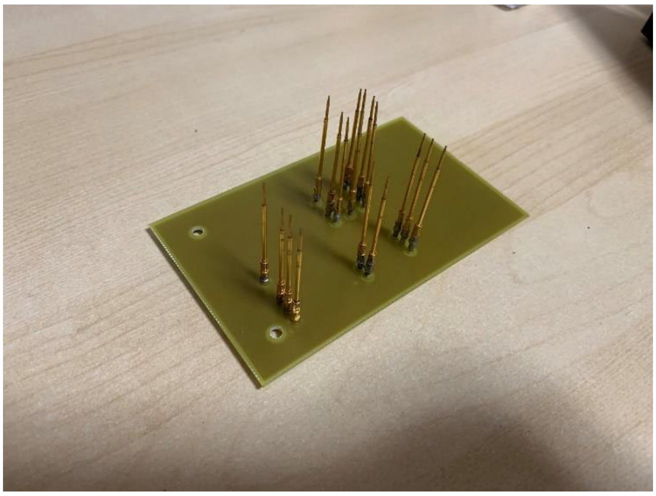

Fig. 7: Bed of nails tester

Of the four main tasks, the URe performs the in-circuit test, while the Fanuc cell uses the iRVision to determine the position of the workpiece and to assemble it. The two robot cells are connected by a conveyor belt.

In industry 4.0 an important requirement is the collection, processing, and application of data [10]–[14] like vibration measurements for predictive maintenance [15]–[18]. Accordingly, each component of the system sends and receives data to the database via the Manufacturing Execution System (MES) (see Fig. 8). This database is also used by the Enterprise Resource Planning (ERP) to assist the management processes [19].

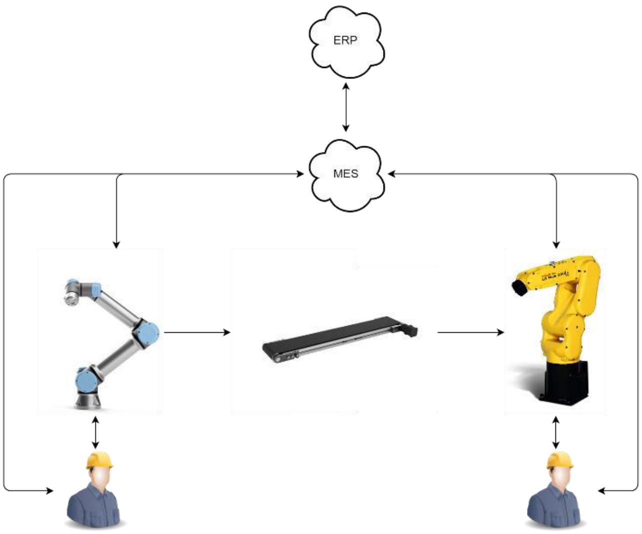

Fig. 8: Hardware architecture

The process is shown in Fig. 9. The UR5e container is filled by an operator, from where the robot arm puts the PCB into the in-circuit tester. If the PCB passes the test, UR5e will move it to the conveyor belt, which will transfer the product to the Fanuc cell. Since the exact position of the PCB is not guaranteed, its position is determined by the Fanuc cell using image processing (iRVision). It then assembles the finished product and sends it to the operator for visual inspection. With both tests, the system provides the option to remove defective products. At the end of the major subprocesses, report generation occurs.

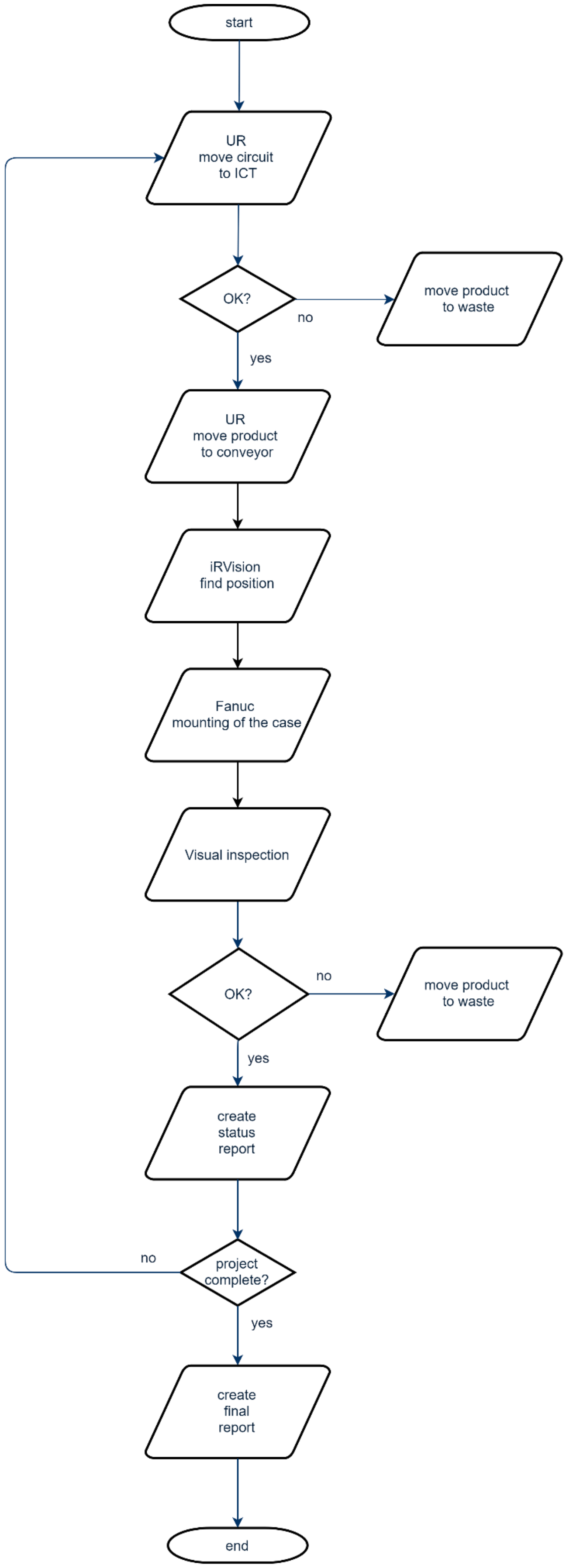

Fig. 9: Process workflow

IV. Conclusion

This paper presents an experimental setup of collaborative industry 4.0 manufacturing cell for educational, development and research purposes. The experimental setup provides an opportunity to compare classical industrial robots with collaborative robots. It demonstrates basic elements of robotic manufacturing and blocks of industry 4.0. This makes the experimental setup capable of teaching, developing and conducting research on cutting-edge technology.

V. Acknowledgement

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