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ROBOTIC CELL CUSTOMIZATION USING AUGMENTED REALITY

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Abstract: *Integrating the Internet of Things into Industry 4.0 necessitates a mix of old and new technological approaches. The cutting-edge technology of the next manufacturing era is Augmented Reality (AR). The problems of the fourth industrial revolution, as well as advancements in AR technology, promise to boost productivity, work quality, user experience, and resource use. The combination of augmented reality and mass customization could meet expanding market demands and client functional needs. The goal of this paper is to use and test an augmented reality application that will allow customers to participate in the design process and solving the Facility Layout Problem within robotic production systems. The AR app will be tested and within an arc welding robotic cell.*

Key words: *Robotic cell, customization, arc welding, augmented reality, facility layout problem.*

1. INTRODUCTION

Designing, configuring, and commissioning individual robots or full robot systems has become more difficult as modern industry has evolved in the framework of Industry 4.0. [1]. Today's enterprises must constantly adjust their industrial layouts in order to meet rapidly changing production targets. The factory planning process has been organized and defined in a variety of ways, and it includes various layers of a production site's hierarchy. The procedures and decisions mentioned in this paper pertain to the layout of components (such as spaces, machines, and other equipment) in a single manufacturing plant [2].

The overall goal of these planning stages is to create a good, if not optimal, layout of the factory's facilities. The development and evaluation of several solution options in order to determine a preferred version that meets quantitative and qualitative criteria is a common principle [3]. As a result, there exist a variety of definitions for single or multidimensional targets (e.g. minimized transportation costs, maximized flexibility). They are frequently dealt with through intuitive decision making based on the planners' expertise, individual preferences, or multicriteria decision making using spreadsheets and scoring models or the Analytic Hierarchy Process (AHP) [4][5]. In mathematical optimization and operations research, a wide toolkit of modelling approaches and solution methodologies has been established, and these findings are contained in the facility layout planning problem (FLP) and its derivatives [6]. Reference [7] provides an organized literature survey that includes a study of layout problems, their mathematical representation and formulation, and resolution approaches. Within reference [8], a thorough research was carried out, with a particular focus on its optimization strategies. As a result, FLPs for existing manufacturing plants have the following features [9][10]: (1) Existing facilities and equipment are major constraints; (2) the relevance of FLP is waning because most technological improvements entail the removal and installation of various equipment and machine tools; and (3) performance criteria are frequently ad hoc and task-specific. As a result, the algorithmic approach to FLP is inefficient in dealing with these challenges. Individual robots or full robot systems can benefit from augmented reality (AR) applications in the design, configuration, and commissioning process [11]. Customers can become a part of the robotic cell customization process by using AR technology to build and verify a specific robotic cell configuration on-site [10][8]. With this objective in mind, this research is being carried out with the goal of highlighting the benefits of using AR applications in the rapid development of FLPs that are tailored to the specificities of the manufacturing process and are based on real-world layouts. The improved feeling of reality can promote the full use of users' experience, knowledge, and intuition in order to identify the specific challenges to be handled within a robotic cell and to review the on-site development plans [12].

Within this article we will highlight how the AR technology can be used successfully for design, configure, and program different robotic systems.

The paper is structured as follows. Section 2 presents the Related Work regarding use of AR within FLP. In Section 3 the Methodology is presented and in Section 4 a Case Study on a robotic arc welding cell is highlighted. Finally, in Section 5 the Conclusions are given followed by the References.

2. AR TECHNOLOGY IN ROBOTICS

Mobile displays (tablets and smartphone screens), computer monitors, Head-Mounted Displays (HMDs), and projecting systems can all be used to create an Augmented Environment, which eventually leads to the creation of Spatial Augmented Reality. (SAR) [13]. In terms of using AR to various aspects of industrial robotics, such as programming, industrial robot programmers were requested to design the Tool Center-Point (TCP) of a robot end-effector, as well as trajectory and overlap instructional duties. The efficiency of the performed labor, the overall time taken to accomplish the task, and the amount of mental strain encountered by the robot programmer were all employed as evaluation measures in this study. The following patterns were discovered [14]:

1. The cognitive load incurred by AR-assisted users was significantly lower than that experienced by users performing activities without AR assistance, and
2. the time spent completing the activity with AR support was much longer for non-experienced AR users. As can be seen, AR technology has the potential to reduce industrial workers' mental strain; yet workers will require time and training to become accustomed to the AR system.

The augmented reality capabilities could allow for exact placement of a robot on the shop floor, allowing for a better knowledge of how it will fit into the space [15]. It's also possible to scale the robot to the required size, alter station rotation to see it from any perspective, and use the timeline tool to monitor the cycle time and jump to a certain point in the animation rapidly.

3. METHODOLOGY

When AR is considered as a value-adding strategy in factory layout design, the potential benefits point to the need for an organized approach. The following is a framework for this method, which is also illustrated in Figure 3.

The potential benefits of AR as a value-adding strategy in factory layout design highlight to the need for a well-organized approach. The typical production planning process is made up of sequential, partially parallel operations with iterative decisions. However, if distinct judgments in detailed planning are taken, adjustments to previous specifications may have a complex and costly impact. As a result, working toward frontloading or early incorporation of dominating fine layout components into AR to assess it impact from an early project phase forward could be a useful method[16].

As previously said, one of the most common and essential examples of such aspects is the energy infrastructure. Thermal losses and their impacts in factories, for example, may be related to conduit length, which might be used as a new optimization criterion. In the planning phase, this early acceptance of fine layout aspects means a well-structured definition of general requirements among project stakeholders. Furthermore, data collection and preparation become even more important in the definition of relevant metrics. Target functions, as previously said, should be able to analyze a need as precisely as feasible, but their impact on the search process' efficiency must be addressed consistently. Finally, when AR is used in industrial layout design, the selection and adaptation of appropriate algorithms and modelling tools is moved to the early planning phases [17].

The primary goal of this technique - utilizing AR to facilitate FLP for current shopfloors in robotic cell modification - is to demonstrate the use of a tool that allows for exact positioning of a robot on the shop floor, allowing for a better knowledge of how it will fit in the space. It's also possible to resize the robotic system to the required size, rotate the station to examine it from different angles, and use the timeline tool to verify the cycle duration and jump to a certain point in the animation rapidly.

The final stage of the automation solution creation process is on-site verification using the AR software tool of the generated robotic system. Resolving the FLP is the first step in this process [2]. The FLP tasks' objectives, such as minimizing material handling costs, and the constraints, such as physical interference between equipment, are viewed as limitations to reaching ideal layout plans [18].

The basic criteria for FLP of an existing shopfloor are generally particular to the process needs; users may only be able to recognize and fix FLP aspects while they are in the shopfloor. Users frequently must establish the criteria and alter their contents individually to resolve this issue. The following are the criteria that are commonly used to define an FLP: [9]:

FLP#1: Data flow optimization to simulate data flow optimization challenges, such as material handling cost optimization, personnel optimization, information flow optimization, and so on, the equation 1 is applied [19]. The unit cost, the distance and the volume of the data transferred from facility *i* to facility *j* are noted as c_{ij}, d_{ij} and respective v_{ij}.

$$FLP_1 = min/max \sum_{i,j=1}^{n} c_{ij} d_{ij} v_{ij} \quad (1)$$

FLP#2: Space utilization the 3D space occupied by the group of equipment, robots, and machine tools is assessed by using the equation 2 [20]. The measurement uses the ratio between the volume of the bounding box that contains all the integrated equipment (V_u) and the volume of the design space (V_{DS}).

$$FLP_2 = min \frac{V_u}{V_{DS}} \quad (2)$$

FLP#3: Distance maximization/minimization distance-based criteria, e.g., maximum distances between certain facilities, minimum distance for frequent facility maintenance, etc. is defined (Eq. (3)) is used to define d_i is the distance between the facilities considered (both the Euclidean and the rectilinear distances are supported) and c is the cost per unit length which needs to be collected and input manually [21].

$$FLP_3 = min/max \sum_{i=1}^{m} d_i C \quad (3)$$

The assessment criteria must be considered in addition to the requirements for defining and solving an FLP. These evaluation criteria take the form of restriction functions (RF) that users can utilize to place restrictions on specific capabilities. The constraints, unlike the FLP definition criteria, set the rules for the individual production facility.

The restriction functions are as follows [16]:

RF#I: Collision detection is used to look for any potential conflicts between the robots and the auxiliary equipment or work object.

Collision detection technology can considerably improve a robotic system's functioning and safety. Collision detection software is usually available as an add-on for traditional industrial robots, but it is included as standard with collaborative robots as one of their primary safety features.

RF#II: Orientation constraint imposes restrictions - certain robots or equipment, for example, must be put in a precise orientation based on the postures of the facility. The following steps will be completed during the planning process: (1) retrieve the current orientation matrix rco and calculate the final rotation matrix; and (2) calculate the rotation matrix rdo from the default orientation to the desired orientation (4):

$$rRFII = r_{do} \times r_{co} \quad (4)$$

RF#III: Space constraint reshapes the amount of space required for the facilities. When a piece of equipment is installed on a shop floor, additional space may be required for maintenance, safety, and other reasons. This constraint is built into the application to allow users to interactively resize the equipment.

RF#IV: Location constraint specifies the valid zones in which to locate a piece of equipment or a facility. To set up the placement restriction, users must first designate a planar surface in the shopfloor, such as the floor, and the facility's contacting surface, such as the footprint.

4. CASE STUDY

Figure 1 depicts the results of a simplified FLP task. The robotic cell including a robot pedestal, an industrial robot, a part positioner, and an end-effector, will be installed as part of this project.

The RobotStudioAR Viewer was used to demonstrate the use of an AR software application that permits exact positioning of a robot on the shop floor, which helps to a better knowledge of how it will fit in the space. It's also possible to resize the robotic system to the required size, rotate the station to examine it from different angles, and use the timeline tool to verify the cycle duration and jump to a certain point in the animation rapidly.

Table 1 depicts the equipment restrictions to be imposed on the production facility, whereas Table 2 depicts the factors to be considered when establishing the task.

Table 1

Restrictions to be imposed on the equipment/facilities

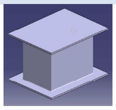
Equipment	Restrictions to be imposed on the facilities
	Industrial Robot ABB IRB 1600 RF#IV location constraint: on the pedestal. RF#I detection collision. RF#III for operational purposes, there is a space constraint.
	Arc welding torch RF#III For operational purposes, there is a space limitation. RF#I collision detection. RF#IV location constraint: mounted on the robot.
	Part positioner IRBP D600 RF#III space constraint for operation purposes. RF#IV location constraint: on the floor. RF#I collision detection.
	Robot pedestal RF#IV location constraint: on the floor. RF#II orientation constraint: the base is on the ground.

Table 2

Process criteria

Criterion	Data and contents
C1: Minimize space between equipment	The space occupied by the robot and the part positioner must be minimised
C2: Minimise 3D space utilization	The generated solution has to be compact such as the 3D necessary volume to be minimised

To be able to use the augmented shopfloor environment, and to implement the robotic cell we must execute the following steps:

- Establish the desired layout by integrating the equipment – using the RobotStudio library for importing the equipment and the created parts. The entire layout of the welding cell will be developed in the virtual environment.
- Robotic cell programming – Using the established layout, the entire process of robotic welding will be programmed using the on-line method.

IRB 1600-6/1.45 is the specification code for the industrial robot that will be used in the robotic arc welding cell. The robot is an IRB 1600 model with a six-kilogram payload and a reach of 1.45 meters, according to the code. This robot has proven to be dependable in a variety of engineering sectors. The following components have a direct relationship with the industrial robot. With the help of the robot pedestal, the industrial robot is elevated into space (Figure 4 and table 1). The pedestal lifts the robot to a height of 620 millimetres, giving it a full 100 millimetres of space beneath the point of fixation.

Due to the nature of our application, more specifically the operation of arc-welding a sheet-metal part, the end effector of our industrial robot is an arc-welding gun – a welding torch (Figure 4 and table 1).

The part positioner and the related components: similarly, to our previously discussed industrial robot, the part positioner present in our arc-welding system, is also developed by the ABB group. To be more specific regarding the version of the positioner, the following manufacturing code is related: ABB IRBP ID 1600. The code describes the part positioner as having a handling capacity of 250 kilograms and a distance between the two mounting flanges of 1600 millimetres. When it comes to the part positioner the following components (Figure 4 and table 1) are in direct relationship. Mounted between the part positioner flanges the steel welding table is positioned. Directly on top, our welded part, which will now be referred to as the work object, is fixated to the welding table with the use of a metal variable clamp. The complete arc welding robotic cell developed in RobotStudio© software application can be seen in Figure 4. Next step in the implementation in our approach will be the programming of the generated arc welding robotic cell. In order to do this, first the welding operation has to be defined.

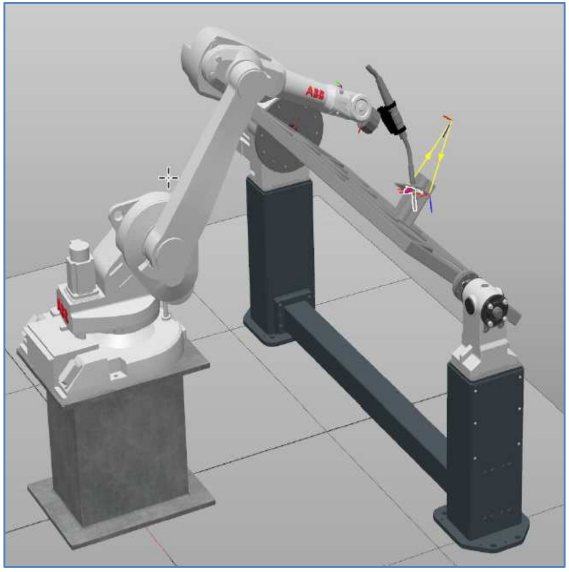
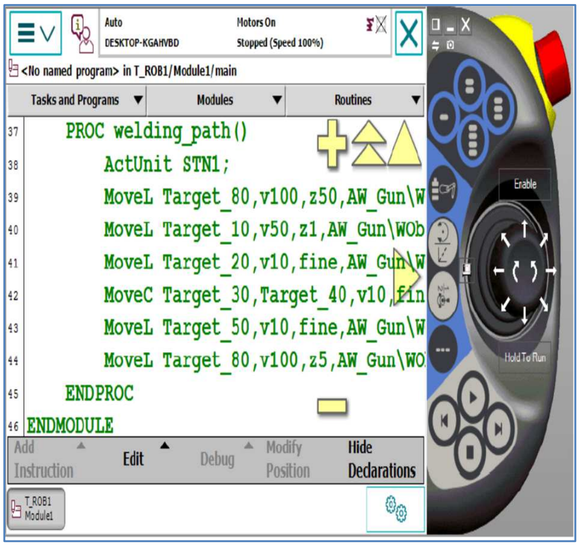


Fig. 1. Virtual prototype of Arc-Welding cell layout developed in RobotStudio®.

A weld will be performed between two adjacent surfaces. One of them pertains to the larger, already welded, set of sheet metal plates while the other is attributed to the single angled plate in the middle of the part. The angled plate is held onto the ensemble using several point welds. In order to cover the entire weld path, a set of five target points will be defined (Fig. 1.).

The points will be placed on the intersection between the two surfaces, and each target points will a different robot programming line. Using the “Autopath” function the previously described target points will form the path that the robot must follow. The generated program is highlighted in figure 2.



```
    PROC welding_path()
        ActUnit STN1;
        MoveL Target_80,v100,z50,AW_Gun\W
        MoveL Target_10,v50,z1,AW_Gun\WOb
        MoveL Target_20,v10,fine,AW_Gun\W
        MoveC Target_30,Target_40,v10,fin
        MoveL Target_50,v10,fine,AW_Gun\W
        MoveL Target_80,v100,z5,AW_Gun\WO
    ENDPROC
ENDMODULE
```

Fig. 2. Welding path highlighted in Flex Pendant.

With all the procedures, orders of operation, speed and layout established the virtual model of the arc welding cell is now prepared to be deploy and evaluate with the AR software. The next step is to prepare and implementation the simulation for the augmented reality tool. In preparation for the augmented reality simulation of the arc-welding process, the file that withholds the data regarding our robotic cell must be exported in the format supported by the augmented reality application - RobotStudio® AR Viewer. In order to obtain this, we have to simulate the welding process and record the simulation - select the Record to Viewer button. This will prompt the simulation to run and at the end of the process, a saving window will appear. In order for our file to be usable in the augmented reality simulation, it has to be saved as a glTF file or .glb file.

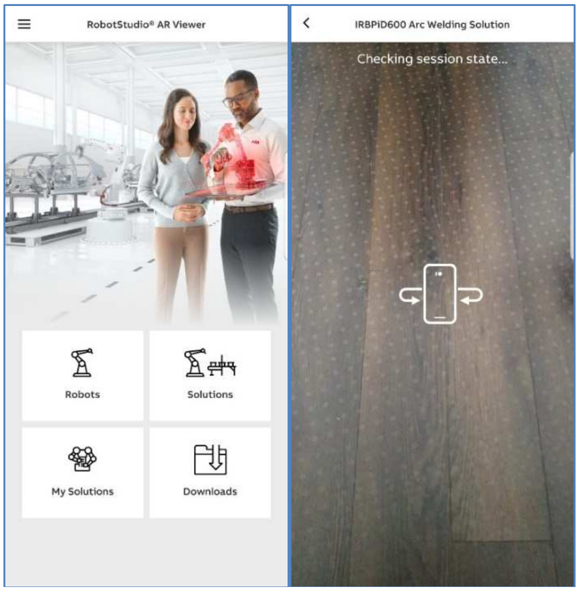


Fig. 3. RobotStudio® AR Viewer – Android capture.

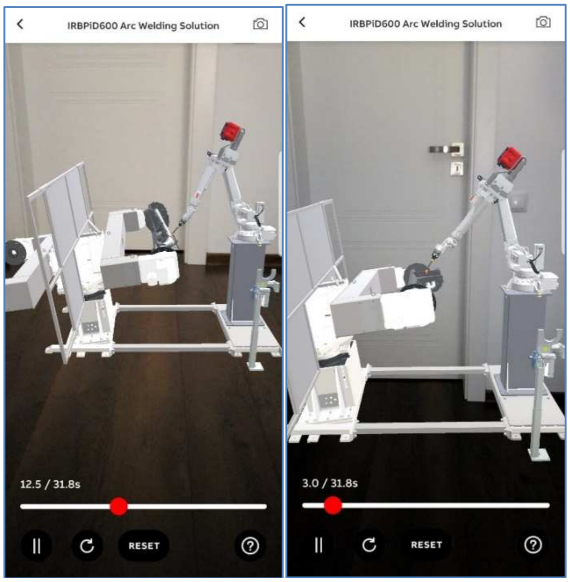


Fig. 4. RobotStudio® AR Viewer – Android capture – Arc Welding Solution.

In order to activate a simulation into the RobotStudio® AR Viewer, My Solutions function has to be selected, and at this point the application will deploy the augmented reality simulation medium (Fig. 3). By panning the already opened smartphone camera the app will proceed to recognise the surface of the floor that it is pointed at, and the augmented reality simulation will be deployed (Fig. 4). The robotic arc welding cell developed in RobotStudio from this point forward, allowing users to obtain a notion of the size and scale of each component of the robotic cell, as well as how it may be placed on a factory floor to fit around any current production equipment. The program overlays the modelled solution into the real-life production area using augmented reality technology, allowing users to scale it to full size and rotate it via a number of angles to get the optimal result. The AR Viewer's advantages go beyond being able to observe the model in action. A timeline tool allows you to rapidly monitor the cycle time and jump to a specific point in the animation, allowing you to improve performance or spot a potential issue.

5. CONCLUSIONS

This research demonstrates that an AR-based solu-tion for existing shopfloors could be used for de-veloping and on-site testing an already generated FLP. The criteria and constraints have been set based on the on-site characteristics, and users can customize the FLP using the AR app to better match the needs industrial process. A robotic arc welding cell was used as a case study to demonstrate the utility of such an AR application. The AR app's ad-vantages include the fact that it is a low-cost, safe, and simple way of visualizing an FLP; there are no issues about hygiene or nausea, which can occur with VR-based alternatives. The AR app used to test the developed FLP system have the following weak points: it can become useless for large-scaled and sophisticated layouts; mobile phones must be per-formant to allow the AR app to run smoothly. To solve these difficulties, more study will be done in the future.

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PERSONALIZAREA CELULELOR ROBOTIZATE FOLOSIND REALITATEA AUGMENTATĂ

Rezumat: Integrarea Internet of Things în Industria 4.0 necesită o combinație de abordări tehnologice vechi și noi. Tehnologia de ultimă oră a următoarei ere a producției este Augmented Reality (AR). Problemele celei de-a patra revoluții industriale, precum și progresele în tehnologia AR promit să sporească productivitatea, calitatea muncii, experiența utilizatorului și utilizarea resurselor. Combinația dintre realitatea augmentată și personalizarea în masă ar putea satisface cerințele în creștere ale pieței și nevoile funcționale ale clienților. Scopul acestei lucrări este de a utiliza și de a testa o aplicație de realitate augmentată care va permite clienților să participe la procesul de proiectare și să rezolve problema de amenajare a instalațiilor în cadrul sistemelor de producție robotizate. Aplicația AR va fi testată și într-o celulă robotică de sudare cu arc.

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