Simulation based Feasibility Analysis of Autonomously Movable Robot Arm

Kristo Vaher¹, Kashif Mahmood², Tauno Otto², Jyri Riives²
¹TTK University of Applied Sciences, Tallinn, Estonia.
²Tallinn University of Technology (TalTech), Estonia

*E-mail: vaher.kristo@gmail.com

Abstract. The use of industrial robots in production is rapidly growing. However, the vast use of industrial robots and implementation of new manufacturing technologies are mostly adopted by large industrial companies. It is due to the nature of the production volume, as robots have a lot of the same kind of work in one specific position in the production process. In smaller companies, where the robots often do not have enough workload in a single specific workplace, the process of robotization has not been so successful. SME-s need a solution where the robot can be moved from one workplace to another in order to utilize the resources like robot arm efficiently. This paper aims to analyse the feasibility for the usage of a robotic arm (a collaborative robot) to serve more than a single production cell intermittently. Production machines are located at particular distance and the movement of the robotic arm between the machines is carried out autonomously with the help of an autonomous mobile robot. Moreover, simulation and 3D visualization were used to conduct and analyse the two different scenarios. Utilization of production equipment assigns as a key performance indicator of the comparison.

1. Introduction

In manufacturing industry, the automation via robots for different applications is inevitable, the recent evolvement of the Industry 4.0 concept and new industrial communication technologies like internet of things in manufacturing led the automation to the level of autonomous.

The applications of industrial robots (industrial robots are automated, programmable and capable of movement on three or more axes) are observed mainly for repetitive and high-precision tasks or monotonous tasks demanding physical effort. The development of collaborative robots ensures the safe working condition for human workers and it allows human workers to confidently share the workspace with robots [1]. It means there is omission of fences for industrial robots and utilization of space can be increased on the factory floor. The new industrial robots can have an ability to move freely and can execute several complex activities just like humans [2]. Furthermore, the free movement of cobots (collaborative robots) in the shop floor enables better utilization of surface area in production and enhanced the usage of resources, possible reduction in costs for automated cells, timely and easier access to the process machines and lower downtime, it may encourage smaller companies to implement robotic solutions [3]. One of the possibilities to autonomously move a robotic arm among several machines is to use the Autonomous Mobile Robot (AMR) platform and mount a robot arm on the AMR. Calibration of the robot arm position relative to the workstation is solved in the authors previous article [8].
The feasibility to analyse a change or test a solution can be performed digitally by creating a similar scale virtual environment and simulate it. In the digital manufacturing context, the use of simulation tools allows the performance evaluation of manufacturing systems and production cells with the help of certain performance indicators [4, 5]. In this case, the physical resources are not needed to acquire and the changes can be validated through a digital manufacturing approach [6].

There are articles analysing the need for mobility of industrial robots [7, 8] and identified possible solutions for doing so. It was analysed that the solution for moving a robot should be manual by a human or automatically by a mobile robot [7]. The automatic positioning accuracy of the robot arm moved by the mobile robot was analysed using machine vision [8]. There have been interesting approach [9] for replacement of manual work by hybrid production using autonomous dual arm robots, enhancing operator working conditions and maintaining the same production levels. Nielsen et al showed in [10], that mobile robot arms can continuously perform meaningful industrial tasks as so-called bartender concept in Cloud Manufacturing (CMfg).

This article analysed the efficiency and cost-effectiveness of a solution where robot arm is moved by mobile robot. A 3D simulation software is used for this purpose. The aim of the simulation is to analyse the different production scenarios of an autonomously moving robot and to compare it with a situation where people do the same work.

The research was done in the framework of development of semi-industrial Industry 4.0 Lab, involving robotised production line, 3D printing stations and automatic storage system (see Fig 1).

![Figure 1. Semi-industrial Industry 4.0 Lab with autonomous cobot platform](image)

### 2. Description of simulation

In the simulation (Fig.2), the Robot Arm (RA) is moved from Work Position 1 (WP 1) to work position 2 (WP 2) by a Mobile Robot (MR). Upon arrival at his work position, the robot arm positions it’s self-relative to the workplace using machine vision. Once the position has been detected, the robot arm connects itself to the communications network using a special plug. The start signal is transmitted to the MES system, which in return sends the correct command to start the correct program inside the robot arm controller. Communication between MES and RA and MR is made via WiFi (IEEE 802.11). At the end of the work, the robot disconnects itself from the communication network, transmits a signal that the work is finished and waits for transport to the next task. The whole process takes place without human interaction.

Two different use cases were analysed. Use case A is a common way how robot arm is used by SMEs. Use case B is a new method proposed by author where robot arm is moving constantly between WPs to execute tasks and reduce downtime.
Figure 2. Robot arm (RA) moved by mobile robot (MR) between working positions (WP 1, WP 2). WM 1 and WM 2 are working machines, H – is home position for mobile robot.

2.1. Use case A
- Two workplaces, one robot arm, one mobile robot.
- Lot size 8 pieces (parts that are produced with machines, see Table 1)
- Operation time for machine 1 is 3 minutes per part and for machine 2 is 5 minutes per part.
- All parts are produced first in machine 1 (WM 1) and then goes to machine 2 (WM 2). Robot stays with machine 1 until parts are ready and then moves to machine 2 and stays there until all parts are done.
- The Mobile robot leaves after it has moved the robot arm.

2.2. Use case B
- Two workplaces, one robot arm, one mobile robot.
- Lot size 8 pieces (parts that are produced with machines)
- Operation time for machine 1 is 3 minutes per part and for machine 2 is 5 minutes per part.
- Machine 1 and 2 are working at the same time. Robot arm is moving constantly between machine 1 and machine 2.
- The Mobile robot leaves after it has moved the robot arm.

Data that is collected from use cases are working and hours of mobile robot, robot arm and working machines. In parallel, a mathematical calculation was performed with parameters given in Table 1. for the use cases and compared with the simulation results.

Table 1. Input data for mathematical analyse

| Name                              | Value     | Formula unit |
|-----------------------------------|-----------|--------------|
| Lot size                          | 8 parts   | x₁           |
| Time to insert part to WM with RA | 15 sec    | x₂           |
| Time to take out part from WM with RA | 20 sec  | x₃           |
| RA positioning time               | 30 sec    | x₄           |
| MR movement time from home(H) to WM1 | 20 sec  | x₅           |
| MR movement time from home(H) to WM2 | 20 sec  | x₆           |
| MR movement time from home WM1 to WM2 | 50 sec  | x₇           |
| Working time of WM1               | 180 sec   | x₈           |
| Working time of WM2               | 300 sec   | x₉           |
3. Simulation data analysis

The set of data obtained from the Visual Components analysis is presented graphically below (Figs.3-4). Comparing the WM 1 and WM 2 utilization of use case A and B, it can be seen that the utilization of use case A is very low but for use case B it is very high, close to 90%. At the same time, a large decrease in production time can be seen. Production time for user case A is 68 minutes and for use case B it is 44 minutes, i.e. the production time is reduced by approx. 35%.

In use case A, it can be seen that the determination of the use of a mobile robot is very low. The average utilization of a MR is 3,8%. For use case B the utilization is much higher, it is 37,5%. It is roughly 10x higher.

Robot Arm Utilization time is given as sum of both work positions (WP 1 and WP 2). For use case A utilization is low, 3,7 %. This is due to the fact that the RA does not work during the working hours of the WM. In use case B the RA is moved between two WP constantly and utilization of RA is increasing almost 2 times. Average utilization of RA for use case B is 6%.
In addition to the Visual Components simulation, the results were also analysed mathematically. In the case of different use cases, the operating time and idle time of the devices were calculated and calculations of operating time and utilization were made on the basis of them (see Tables 2 and 3).

There are some differences between the simulation and the mathematical computer, because it is not possible to enter certain time parameters for the operation of the RA in the visualization program. A mathematical model gives more accurate results than a simulation. Input data units are in seconds. Output values are given in hours.

\[
RA_{wh,A} = \frac{(x_2+x_3)x_1+(x_4+x_2)+((x_2+x_3)x_4+(x_4+x_2))}{3600} \quad (1)
\]

\[
RA_{wh,B} = \frac{(x_4+x_2+x_2+x_3+x_3)x_1+(x_4+x_1)x_2+x_2x_1+x_3x_2}{3600} \quad (2)
\]

\[
MR_{wh,A} = \frac{(x_2x_3+x_2+x_3)}{3600} \quad (3)
\]

\[
MR_{wh,B} = \frac{(x_2+(x_5+x_7+x_9)(x_1-1)+(x_5+x_7+x_9)x_1}{3600} \quad (4)
\]

\[
Total\ process\ time_A = \frac{(x_2x_3+x_4+x_5)+(x_2+1)(x_1+2)(x_1+1)+((x_3+x_2)x_1)}{3600} \quad (5)
\]

\[
Total\ process\ time_B = \frac{(x_4+x_2+x_3+x_4)x_1x_2}{3600} \quad (6)
\]

Average utilization time for RA and MR is calculated as follows:

\[
RA_{ut,x} = \frac{RA_{wh,x} \times 100}{Total\ process\ time_x} \quad MR_{ut,x} = \frac{MR_{wh,x} \times 100}{Total\ process\ time_x} \quad (7)
\]

**Table 2. Working and idle hours of RA and MR**

| Use case (x) | RA<sub>wh</sub> | MR<sub>wh</sub> | RA<sub>ph</sub> | MR<sub>ph</sub> |
|-------------|----------------|----------------|----------------|----------------|
| A           | 0,19           | 0,05           | 1,09           | 1,07           |
| B           | 0,42           | 0,38           | 0,23           | 0,78           |

<sub>wh - working hours</sub>  
<sub>ph - pause hours</sub>

**Table 3. Utilization of RA and MR**

| Use case (x) | RA<sub>ut</sub> | MR<sub>ut</sub> | Total process time |
|-------------|----------------|----------------|-------------------|
| A           | 14,8%          | 3,7%           | 1,28              |
| B           | 38,8%          | 34,9%          | 1,09              |

<sub>ut - utilization, working time from total time (%)</sub>

The results of the simulation and mathematical calculation shows that the results are different. The reason is that simulation software does not have option to add additional time for RA adjustment before starting working with WM. Comparing mathematical calculation of use case B with use case A, it can be seen that the time required for production decreases by about 14% and the use time of RA and MR devices increases significantly by about 2 times.
By changing the input parameters of the process, the performance indicators also change. Extending the working time of the WM significantly reduces the total production time for use case B to compare with use case A. By increasing the distance between the working machines, i.e. by increasing the travel path of the MR, the production time as well as the utilization rate of RA and MR decreases for use case B.

4. Conclusion
The use of industrial robots in SMEs has been modest so far, one of the reasons is the lack of work for the robot in one particular location. Moving the robotic arm between working positions would significantly increase its usability and increase the rate of use of the device itself. This article compared two different ways of using a robot, the second of which (use case B) allows the robot arm to move autonomously between different workstations on the factory site with the help of a mobile robot. Autonomous movement of the robot arm between different work positions significantly increases the usability of the robot and increases production efficiency. As a result virtual production line was added to the Industry 4.0 semi-industrial lab, allowing better pre-planning and faster reconfiguration without stopping the real time production.

References
[1] Kangru T, Riives J, Mahmood K and Otto, T, 2019, Suitability analysis of using industrial robots in manufacturing, Proceedings of the Estonian Academy of Sciences, vol. 68 (4), pp. 383–388.
[2] Barosz P, Golda G and Kampa A, 2020, Efficiency Analysis of Manufacturing Line with Industrial Robots and Human Operators. Applied Sciences, vol. 10 (8): 2862.
[3] Unger H, Markert T and Müller E, 2018, Evaluation of use cases of autonomous mobile robots in factory environments, Procedia Manufacturing, vol. 17, pp. 254-261.
[4] Mahmood K, Lanz M, Toivonen V and Otto T, 2018, A performance evaluation concept for production systems in an SME network, Procedia CIRP, vol. 72, 603 – 608.
[5] Kangru T, Riives J, Otto T, Pohlak M and Mahmood K, 2018, Intelligent Decision Making Approach for Performance Evaluation of a robot-based Manufacturing Cell. Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition: IMECE2018, November 9-15, 2018. Pittsburgh, PA, USA.
[6] Lima F, de Carvalho C, Acardi M, dos Santos E, de Miranda G, Maia R and Massote A, 2019, Digital manufacturing tools in the simulation of collaborative robots: towards Industry 4.0, Brazilian Journal of Operations & Production Management, vol. 16 (2), pp. 261-280.
[7] Vahe K, Kangru T, Otto T, Riives J, 2019. The mobility of robotised work cells in manufacturing. Proceedings of the 30th International DAAAM Symposium "Intelligent Manufacturing & Automation": 10th International DAAAM Symposium "Intelligent Manufacturing & Automation", 23-26th October 2019, Zadar, Croatia, DAAAM International, Vienna, Austria.
[8] Vahe K, Otto T, Riives J 2020. Positioning error correction of autonomously movable robot arm. Journal of Machine Engineering, 20 (6), 152–160.
[9] Kousi N, Michalos G, Aivaliotis S, Makris S 2018. An outlook on future assembly systems introducing robotic mobile dual arm workers. Procedia CIRP, 72, 33-38.
[10] Nielsen I, et al 2017. A methodology for implementation of mobile robot in adaptive manufacturing environments. J Intell Manuf, 28, 1171–1188.