Robotics for SME’s – Investigating a Mobile, Flexible, and Reconfigurable Robot Solution

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Abstract

Today’s business environment is dominated by change and uncertainty, and success within manufacturing is becoming more and more difficult to sustain. Also, many European manufacturing companies experience low availability of human resources and recruitment problems. One way to handle this challenge and improve a company’s efficiency could be to invest in automation and industrial robotics. However, robot automation investments are in many cases still too difficult and too technically advanced especially for small and medium sized enterprises. There is need for automated systems with an acceptable investment, high efficiency, high adaptability, and with such flexibility that it may produce several different products and adapt to future product variants without large additional investments. Thus, the concepts of flexibility and reconfigurability are becoming increasingly important within manufacturing systems and robotic work stations.

The objective of this paper is to investigate the need for flexible and reconfigurable industrial robot systems and to present some possible solutions for how the concept of mobile industrial robotics can be applied within industry, and specifically at small and medium sized enterprises. A conceptual solution for a mobile industrial robot will be presented and evaluated in terms of applicability for a manufacturing SME. The result of this evaluation is that the concept of mobile industrial robotics may be an enabler for SMEs to overcome the barrier to invest in industrial robotics. However, several technical developments have to be accomplished to open up the market for this type of solutions, and the common attitude of the SME would have to be changed to become more receptive to this type of highly technological solution, i.e. the perceived complexity of the highly complex system has to be low.

1. Introduction

Today’s business environment is dominated by change and uncertainty, and manufacturing success is becoming more difficult to sustain. Low-cost and high quality is not enough to sustain a competitive position in market place. Meeting customer demands requires a high degree of flexibility, low-cost/low-volume manufacturing skills, and short delivery times. Success in manufacturing requires continuous development and improvement of how the products are produced. Thus, more and more companies, and especially small and medium sized enterprises (SME’s), are forced to continuously reduce waste and streamline operations towards producing products at lowest possible cost.

The objective of this paper is to investigate the need for automation and industrial robots as well as presenting some possible solutions for how the concept of mobile industrial robotics can be applied within industry, and specifically at small and medium sized enterprises. The results in this paper is based on an ongoing research project; Robotics for SMEs within the program Robotdal en in Sweden. The paper presents the background of this research, including the industrial needs and some earlier research. After this, the paper presents the concept of displaceable industrial robotics and how different such solutions may be classified. Next, the paper discusses whether the concept of mobile industrial robotics can be applied to SMEs, and presents an ongoing research project within this area. Finally, some conclusions and future work will be presented.

2. Background

2.1 The Current Situation for SMEs

This manufacturing challenge is especially important from a European perspective as small and medium sized enterprises (SMEs) make up a large part of the European industry. 93% of all European enterprises have less than 10 employees and only 0.2% has over 250 employees [1]. Enterprises are categorized SMEs if they have less than 249 employees and large sized enterprises (LSEs) if they have 250 employees or more. In Europe 99.8% of the enterprises are categorized as SMEs and only 0.2 % are categorized as LSEs [1].

60% of SME managers state that competition on their market has increased over the last two years [2]. 73% of the large sized enterprises (LSEs) report an intensified competition. Different business sectors see different increase, but in all sectors the majority of the enterprises perceive markets as becoming more competitive.

The SMEs in Europe has reported that the availability of human resources and cost of human resources are some of
the most important business constraints. As many as 35% of the SMEs reported that the availability of human resources was a problem and 33% reported that they experience that the cost of human resources are an important issue [2]. Among LSEs, 33% reports that lack of manpower is troublesome. Less than half of the SMEs managers state that they have no recruitment problems, with the largest limitation being the availability of appropriate workforce [2]. Over half (51%) of the SMEs state that the problem with lack of skilled labor has increased during the last two years, while 57% state that the problem with too expensive labor force has increased during the same time period.

One possible scenario to handle this human resource challenge could be to invest in automation and industrial robotics.

2.2 Future challenges within Manufacturing

The US National Research Council Committee concludes that the competitive climate, enhanced by communication and knowledge sharing, will require rapid responses to market forces [3]. The same report includes six goals identified as needed in order to compete on a global market [3]: (1) concurrency in all operations, (2) integration of human and technical resources, (3) transformation of information into useful knowledge for effective decision making, (4) reduction of waste, (5) reconfiguring manufacturing enterprises rapidly, and (6) developing innovative processes and products with a focus on decreasing dimensional scale.

ManuFuture published another, more recent report on what will be important within future production systems, called Strategic Research Agenda. One of their conclusions regarding what they refer to as advanced industrial engineering is that the development of future knowledge-based factories requires research into adaptive structures and solutions that make provision for continuous change [4]. Some examples of such structures and solutions include the following [4]: management models and systems following the objectives of self-organization and self-optimization, reconfigurable technical systems and integrated processes/systems, technical intelligence in process control systems with efficient human-machine interfaces, and efficient networking in systems based on standards and open system architecture.

A panel report from the Royal Swedish Academy of Engineering Science (IVA) with focus on “Future Production” identifies a number of factors important to consider when designing competitive production systems. These include change [5]: customization, integrated information systems, rapid changeability, robustness, right level of automation, and flexibility in terms of changeovers, production volume, and product variants. These requirements, however, cannot be fulfilled at one time in order to achieve efficient production; the production system needs to be under constant development and change [5]. A higher level of product customization is required. The companies will address this need, in turn, through increased adaptability, flexibility, modularity, and agility in future production systems [6].

Reviewing those different reports presented here, one can see that having a manufacturing system which is agile and can be reconfigured over time will be important for competing in the future. Flexibility and reconfigurability are two important concepts for achieving competitive production.

2.3 Flexibility and Reconfigurability

The concept of flexibility has been extensively researched and published over time. A study performed by Shewchuk and Moodie identified about 70 different definitions and measurements of flexibility described in literature [7]. Flexibility is by many authors considered a necessity for coping with internal and external disturbances [8]. The flexibility of a manufacturing system can be defined and determined by its sensitivity to change [9]. Flexibility can also be seen as a measurement for how many different product variants a certain manufacturing system can handle; what e.g. Browne et al. call product flexibility [10]. Using the definition from Jackson, a flexible system is a system that has been designed in accordance with the ability to deal with changes effectively [11]. In other words, flexibility is the system’s built-in ability to handle change or disturbances. Thus, based on this reasoning, flexibility is defined in this research as the ability to robustly handle short-term changes quickly and at a low cost within an existing production system.

The topic of reconfigurability within manufacturing systems has been researched in an area called Reconfigurable Manufacturing Systems (RMS) (See an overview of the area in, e.g., [12]). In contrast to FMS, designed to have over-capacity, the design of the RMS is to enable easy reconfiguration and responsiveness to change, using a more modular structure for hardware and software [13]. Mehrabi et al. describe an RMS as a system created using basic process modules – hardware and software – that may be rearranged quickly and reliably [12]. Reconfigurability is in this research defined as a systems ability to adapt rapidly in response to changing needs and opportunities [11].

As the manufacturing systems are becoming increasingly flexible and reconfigurable, it is important that the concepts of flexibility and reconfigurability are incorporated into the robotic working cells as well [14].

2.4 Automation and Industrial Robotics

One way to improve a company’s efficiency and handle low availability of human resources as well as recruitment problems could be to invest in modern manufacturing technology as e.g. flexible automation. Ever since the first industrial robots were created to help out, mainly in the automotive industry during the early 1960s, the robot has been used to replace humans in workstations unsuitable for humans due to, for example, heavy lifting, monotonous
movements, or being in hazardous environments [15]. Long accepted by industry as a method for improving quality, performance and efficiency, robotics has for at least three decades been a key technology in manufacturing industries [16]. The industries have employed it to increase industrial productivity and competitiveness in manufacturing. Highly automated production systems with a limited amount of manual work are the kind of system that countries like Sweden, and other countries with a high labor cost, can compete with [5]. For SMEs, automation could be a prerequisite in order to survive in a new market that requires high flexibility, intelligent manufacturing systems and robots [17].

An earlier study shows that the main reasons for SMEs to investigate the possibilities to invest in industrial robots are: (1) eliminate ergonomically unsound workstations, (2) get higher efficiency in workstations, (3) lay-off employees, and (4) higher utilization of manufacturing equipment [18]. The same study showed that the most common application investigated for industrial robotics at SMEs was machine tending.

However, the industrial robot of today is designed from the perspective of a user engaged in capital intensive large-volume manufacturing, i.e. automotive industries. This results in relatively costly and complex robot systems [19]. There is also a problem in creating automated systems with an acceptable investment, high efficiency, high adaptability, and with such flexibility that it grants adaptability to current and future products, without large additional investments [5]. As the business environment for companies, especially SMEs, grants shorter and shorter time horizons when it comes to the life-times for their manufacturing systems it becomes increasingly important that the investments made in production equipment can be reused over several products or projects.

A white paper on industrial robotics produced by Euron identifies a set of different requirements on future robot systems, including [19]: portable or mobile robotics, safe human-machine interaction, interactive instructions and problem handling instead of programming, and low-cost.

A study presented in [20] reports some of the disadvantages with using automation, received through a Delphi study where companies were asked to rank what they had experienced as the main difficulties. The most common answers were: Too many product variants, Adapt the product to automatic manufacturing, and Investment cost. As a follow-up to the first survey in the study, a new survey was distributed where the companies was asked to rank the primary problems with using automation. The most common answer was “lack of competence”, followed by “too many product variants”.

3. The Concept of Displaceable Industrial Robots

This research focuses on industrial robots used for tending manufacturing machines, e.g. CNC lathes or milling machines. The usual setup for such an application is to place a robot in front of a machine, programming it to feed material into the machine and pick material from the machine as it has been processed. It is also common to place several machines around one robot to allow for that robot to tend all machines, saving the cost of purchasing additional robots.

If one wants to tend even more machines with one robot, or if the machines are too large for one robot to reach several machines, a track-mounted robot may be used. The limitation of number of machines tended by a single robot is the cycle time in the machines. The robot should never be the limiting time-factor in a cell, but the machines should decide the overall cycle time.

If one have machines that are used only some of the time, a robot may prove to be hard to pay-off if invested for a certain machine. Many companies needs the robots to work at least two shifts each day in order to consider them a sound investment (based on reduction of human workers). In this case one would like to be able to easily re-use the same robot over several machines, even if the machines are placed in different locations within the factory. Being able to displace the robots enables companies to re-use the robot where needed and can thus pay-off the investment over time.

There are several attempts within the area of displaceable industrial robotics, both completed and ongoing. There are those projects where portable robots are in focus, e.g. the Factory-in-a-Box [21] and the Porthos [22] projects. A portal robot solution means that the robot can be manually moved between locations where it is needed. Brecher et al. justify the research effort in portable robots [22]:

“Nowadays industrial robots cannot be applied for handling small lot sizes in a profitable way because of the high investment costs and installation efforts. In order to open up this new market for industrial robots the robot’s flexibility has to be increased, especially in terms of portability.”

Other projects focus on mobile robots, where the robot moves autonomous in the production system. This approach is more complex and requires the robot platform to be able to navigate in some way. An example of research within this area is described in [23] where the resulting robot is referred to as a Robot Assistant rather than an industrial robot. Mobile robots have also been commercialized by e.g. Denso Corporation, where a standard smaller-sized industrial robot was placed on an AGV to enable autonomous movement along magnetic tapes on the floor [24]. Denso motivated the work on mobile robots with the need for production systems that are responsive to fluctuations in production volumes [24]. However, the mobile robot developed by Denso is discontinued as a product, based on the lack of business case.

Haegele et al. [23] uses production volume and product lifetime as key-characteristics for deciding which type of production equipment to use (Figure 1).

The product lifetime is vital since the shorter the product lifetime, the greater is the need for a system which can be reconfigured for new products or product variants. The development of more reconfigurable robot automation allows for automation even when having lower production
volumes since it enables easy re-use of the equipment.

![Diagram showing uncertain production volume and product lifetime.](image)

Figure 1, the two characteristics production volume and product lifetime mapped in a diagram based on the level of uncertainty in a manufacturing system, adapted from [23].

The production volume is important as well, when deciding whether to use automation. Traditionally a rather high production volume has been considered a prerequisite for using automation. Companies having several products with lower production volumes can design flexible manufacturing systems where all products can be manufactured/assembled in the same workstations, thereby getting a sound return of investment on the automation. There are different ways of dealing with fluctuations or uncertainties when it comes to production volume. One way is to design the production system with an over-capacity, making sure that it can handle any peaks in production volume. However, this leads to over-spending in production equipment and possibly loss of profit. A better solution is to design the production system to be reconfigurable so that it may be changed according to the current needs and opportunities. This, however, requires that the workstations in the system are designed so that they can be scaled according to the current situation, or that new stations can be added when needed. The concept of having mobile robots that can move along the production line, starting to work where the need is greatest at the movement (as described in [24]) is interesting here since it implies that the robot is capable of doing all tasks in the production line, i.e. standardized. Therefore it should be easy to add new robots if the production volume increases, as well as decrease the number of robots when the line has an over-capacity.

Having a certain production volume and product lifetime (the upper-right quadrant of figure 1) makes it easy to design the production system as the requirements of the system are known. The system may be designed to handle a certain capacity and the investments in equipment and resources are easily calculated.

In the case when both the product lifetime and the production volume is uncertain, the production system have to be reconfigurable both in the sense of temporarily changing capacity and in order to re-use equipment between product types. Often SMEs end up in the lower right corner of Figure 1, since they are suppliers to other companies and are thus in most cases not able to plan very long ahead.

In summary, one possible future application for robotics is the concept of mobile and displaceable industrial robotics. Industrial robots which are easily replaceable or mobile needs to be versatile enough to handle a large set of products and operations, and may thus more easy to pay-off over time.

One research project investigating this is the project; Robotics for SMEs within the program Robotdalen in Sweden. The goal of the project Robotics for SMEs is to develop a system for automation with focus on flexibility, interactive instruction and mobility. One of the deliverables of the project is a demonstrator, showing an industrial robot placed on a mobile platform. The robot is programmed using intuitive programming methods such as hand gestures, and a flexible gripper is designed so that the mobile robot arm is capable of handling several different types of products.

One of the research topics in the project is the design of flexible and reconfigurable robot automation (DIRA). The DIRA sub-project focuses on how to design and manage flexibility and reconfigurability within robotic working cells, as well as investigating how to reduce the perceived flexibility of the automated working cell.

4. Simplicity in Flexible and Reconfigurable Robotic Working Cells

Today when industrial robotics is integrated into a production system the installations are often custom-made for that specific installation and a considerable amount of engineering time is put into designing fixtures, grippers, and software programs. In a lot of cases, the end solution is a fenced in robot with a rather complex set of technological equipment and control programs. In an ongoing project called “Future Production Plant – Lean Robotics” the needs of a world class manufacturing system, in terms of industrial robotics, are investigated. As reported in [25] the situation of the studied case company was that the human operators on the factory floor had little confidence in that they themselves could implement changes in their own robotic working cells. The fact that the company did not have the competence to introduce new product variants or fix smaller problems in the working cells leads to a strong dependency on external consultants and system integrators. Looking at the needs of the case company described in [25], one can see that the problems investigated in that project are very much similar to the problems that many SMEs are experiencing with their industrial robot automation. Some of the key-enablers discussed in the Lean Robotics project as vital for future robotic working cells are: increased ease-of-use, intuitive user interfaces, and better ways to visualize what is going on in the cell. This is the same focus as there should be on robotic working cells designed for SMEs which often lack expertise and experience within the area of industrial robotics.

As part of the Robot to Thousands project, which also contributed to the results presented in [18], studies have
been made on the different reasons to why SMEs are sometimes reluctant to invest in industrial robot automation. Some of the main barriers for SMEs to invest in industrial robotics are: investment costs and the need for expertise and experience.

As seen in the studies presented earlier there is a need for more flexible and reconfigurable robotic working cells. However, as one adds more functionality and features to the manufacturing system, the system tends to become more complex, i.e. the user needs more competence to use or modify the system. This is in a lot of cases unavoidable. Hence, it is important, as a system designer, to continuously work to decrease the perceived complexity of the system. This can be done, for example, by having clear and well-defined human-machine interfaces, wizards or similar guiding functions, and a high level of autonomy in the control software. This is the focus of the DfRA sub-project in Robotics for SME. The project team is currently investigating the need for easy cell-level programming of robotic working cells, as well as the need to visualize the current state of production. As shown in the earlier project Factory-in-a-Box, as well by others e.g. EIMaraghly [26], it is important to consider software when designing manufacturing systems for reconfigurability. Finding hardware solutions for reconfigurability is often more easy than to implement software support for the same [25].

5. Conclusions

The objective of this research was to investigate the need for mobile industrial robots and present some possible solutions for how the concept of mobile industrial robotics can be applied within industry, and specifically at small and medium sized enterprises. During this study, a review of current systems for mobile industrial robots has been performed, as well as a survey of current trends within the area of manufacturing and industrial robotics. A background section presented some of the current needs of the SMEs in Europe as well as introduction and definition of the concepts of flexibility and reconfigurability.

The second section of this paper discussed the current needs for companies, and especially SMEs, within Europe as well as some current challenges within manufacturing. One of the conclusions from this section were that there is a need for an increased level of automation within industry, both in order to receive a higher productivity, eliminate dangerous or ergonomically unsound workstations, and in order to reduce the recruiting issues.

The third section of this paper presented one suggestion of an enabler for how to make industrial robotics more capable and available, i.e. that displaceable robots may be a solution. There are several ongoing research- and commercialization projects within this area. Being able to have one robot tending several machines is one way to ensure a sound return on investment when purchasing robots.

One important thing to consider when designing robot automation is to reduce the perceived complexity of the system, as discussed in section four. A rule of thumb can be that the more functionality built in, the more to keep track of for the operator. There is a need from industry to increase the level of flexibility in the manufacturing systems. This combined with the need for more automation, incite for research in the area of flexible robotic working cells. There is also a need for reconfigurability, i.e. the ability to change the capability or capacity of a manufacturing system to match current needs or opportunities.

The vision of the Robotics for SME project is to enable companies to invest in one industrial robot placed on a mobile platform so that it may tend several machines, located in different parts of a factory. This is suggested to be an approach where the company may invest in one robot, which is then re-used over several machines and products. This requires a robot system which is very flexible so that it may handle several product types or variants, and adaptable so that it may easily be configured for new products or routes through the factory.

There can be somewhat of a challenge to add new functionality without increasing the complexity of the manufacturing system. This means that it becomes increasingly important to investigate how to ensure that the end-user will be able to manage the system. This is especially true when the end-user lacks special automation skills and experience, as is the case with most SMEs. Future work within this research project is to map the needs of the end-users and see how one can support the SMEs so that industrial robot automation becomes more available for them. The main focus will be on user interfaces and on how to improve the working cell structure or interfaces so that it becomes more visible what is going on in and around the cell during production.

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