Human centered Lean automation in assembly

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Abstract

Empirical studies have documented skills that make humans superior to machines in various contexts while keeping them inferior in some others, nevertheless; humans are recognized as the most flexible element in a production system. This paper relates the theory of Lean automation with human-machine interaction; thereby taking benefits from the bests of humans and machines in a combination. The result is biomechatronic production systems. We present a framework that discusses the physical, sensorial and cognitive capabilities of humans; and the technologies that can enhance them. One technology for each capability enhancement has been selected and is evaluated for ease of use and industrial applicability in assembly tasks.

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1. Introduction

The constant battle for shortening product life cycles has been among the most impactful changes to the business world in recent decades. This booming demand for new products means that companies need to reduce time-to-market and supply chains need to adjust to withstand this increasing pace. This requires that companies constantly need to be aware of the new technologies and the opportunities these technologies can create [1]. The groundbreaking transformation of economy is likely to happen under emerging technological developments for smart manufacturing [2].

Assembly of fabricated parts accounts for over 50% of total labor cost associated with the product, 25-30% of the total cost of any manufacturing company and one-third of the people employed in the manufacturing sector [3]. Manufacturing excellence of assembly work can serve as a strong tool to achieve competitive advantage through automation and digitalization. But complexity and dexterity requirements in assembly still make humans a vital asset and therefore assembly has traditionally been resistant to mainstream automation.

Manual production has imposed flexibility and cost related challenges in the time of globalization. The challenge of increasing automation while remaining cost effective and flexible is the goal for manufacturers in high wage economies. Semi automation is ideal with human centricity [4]. This is in-line with the studies [5] investigating full automation and it was concluded that automation must be designed with humans as an integral part of it.

Several emerging smart technologies can complement the capabilities of human operators working in assembly cells to automate a proportion of their tasks thereby moving further towards automation and productivity while being flexible. The objective of this study is to discuss the vitality of humans for Lean-automation in assembly cells. By considering an industrial case of a manual assembly work station the potential effects on future workers in context of human capabilities are discussed.

We propose a framework for designing human centered Lean automation that forms a theoretical foundation for having humans integrated with technologies complimenting an ideal human-machine interaction.
2. Relation to existing theories and work

2.1. From Lean production to Lean automation

The philosophy of Lean production finds its roots from Toyota Motor Corporation in their manufacturing best-practices such as Just in Time (JIT) management, Quality Management (QM), Total Productive Maintenance (TPM) [6]. The primary characteristics of Lean production are elimination of wastes, focus at value adding activities and strict integration of humans in the production process. Over the last decades Lean philosophy has been embedded in many manufacturing industries. The advantages of productivity increase of up to 25% in addition to being simplistic are reasons that Lean has been well-known and used in Western economies since the 1990s. However, given the fact that the Lean production method originated in the 1950s, it can fail to consider the potential of ICT (information and communication technologies) developments that have taken place in recent decades [7].

Already in 1990s, first attempts were made to combine Lean production with automation technologies. Since then there was little attention in research directed towards Lean automation, but with the emergence of the Industry 4.0 paradigm and advances in ICT and digitalization technologies, Lean automation has experienced a re-emergence in recent years [8]. While some first Lean automation solutions have been developed, they are proprietary solutions which must be tailored to the individual needs [8].

Jackson [9] documented a definition of Lean automation as: “Lean automation is a technique which applies the right amount of automation to a given task. It stresses robust, reliable components and minimizes overly complicated solutions.”

The concept of Lean automation was an emergence of an existing concept in Lean literature referred to as autonomation or automation-with-human-touch. Using automation with a human touch, Taiichi Ohno at Toyota, redefined the Japanese term of Jidouka. The original meaning of Jidouka was automation and later changed with the addition of two extra lines referring to humans, thus adding the human element in the automation system [9].

Contrary to the idea of CIM (Computer Integrated Manufacturing), which is a previously established concept for manufacturing automation in which the fully automated factory without light, heat or employees was a vision, Lean automation is concerned with finding the right level of automation. Here, Bilberg and Hadar [10] presented Lean semi-automated cells, where the automation is focused around the manufacturing process, while the planning, the material flow and part of the inspection is handled by the employees. This conception was later cited in Lean automation literature [7].

2.2. Human capabilities in assembly

Capability is defined as the objective-achieving property of an entity that helps realizing the overall mission of it. For human beings, this describes having the resources and ability to accomplish the desired task. In manufacturing, manual works are sensomotoric tasks requiring coordination of brain-motor skills and the human sensing/cognition system. An example of which is hand-eye coordination, or haptic perception. Mental work of requiring information reception, processing and decision making is an integral part of it. As humans grow older, a progressive change in these capabilities has been reported through many studies elucidating the positive and negative effects of aging on human capabilities. For example, the human dexterity is reduced by 30% between age 20 and 60 [11].

A growing research base is getting available examining human capabilities involved in manual work and the changes observed when interacting with automation [12].

Assembly automation has often been referred to as the mechanization of physical tasks. However, assembly process is a complex process with both physical and cognitive tasks. Physical tasks are the basic tasks such as handling, joining, screwing etc. and cognitive tasks deal with control and support of physical tasks [13]. A compelling work in this regard is presented by Romero [14] to identify the capabilities of humans in production systems and to model a classification of human capabilities as physical, sensing and cognitive.

The capability classification [14] is further described as: (a) Physical capabilities, are the humans’ capacities to undertake physical work, characterized with multiple attributes of physical functions (lift, walk, manipulate) and non-physical functions (speed, strength, precision); (b) Sensorial capability, is the capacity of an operator to collect and use data from the environment to accomplish the daily tasks. Sensing has two components where the first component is to collect the data by vision, smell, sound and then to perceive the data; (c) Cognitive capabilities, are defined as operator’s ability to perform mental tasks such as reasoning, decision, perception.

2.3. Degree of automation and function allocation

An increased level of automation is expansive and rigid, yet it requires human intervention in surprising situations. However, a higher level of automation [15] makes it harder for the humans to intervene since the system was designed to keep humans away from the automation [16]. Such problems of increasingly automated and authoritarian systems can be solved by taking humans as an integral and central element of the automation and design a human-centered automation [17]. In asserting the need of human-machine collaboration, Norman [5] emphasized to start automating the systems from the humans by considering their powers and abilities and then transfer the rest of the tasks to the machines.

Norman further explained humans to be good at pattern recognition, dealing with the unexpected and setting high level goals, while humans are found to be not good at performing repetitive operations, producing accurate and precise actions repeatedly and at vigilance for long periods of time with nothing to do until an unexpected event occurs. A classical theory of functional allocation between humans and machines was presented by Fitts [18] and is often referred to as MABA-MABA list (men are good at - machines are good at).

By reducing the human effort and increasing automation in assembly work, the question will arise of defining the right level of automation. Automation should be used for work that
is menial, repetitive and/or ergonomically challenging for humans to perform, while humans must perform more specialized and complicated tasks that cannot easily be automated. Automation of tasks must ideally be started from the more value adding tasks and gradually moving towards tasks with lower value addition. Frohm [13] defined levels of automation as: “The allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic”.

While, fortunately, machines are good at all the tasks humans are bad at and this actuality emphasizes the need of devising collaboration whereby humans and automation are doing what they are best at. Although there are capabilities that are unique to machines and humans and can be used to strengthen the capabilities of each other, yet they both have overlapping capabilities offering the opportunity to assign tasks in variability according to resource availability [19]. The aligned argument is presented by [20] that achieving the appropriate level of automation is a Lean automation.

3. Smart Technologies for assembly automation

Based on authors’ theorizing and literature exploration, the following definition is presented for Lean automation in assembly cells:

“"A human centered Lean automation emphasizes to designate the right amount of automation for a given manual task. It takes care of the physical and cognitive capabilities of humans and machines and forms an appropriate human-machine collaboration with human at the core of the system".

The framework shown in Fig.1. describes the steps for designing Lean automation in assembly cell with a human centered design approach. The process starts with decomposing the tasks in an assembly process

The next phase is a process of analyzing each manual task for the human skills needed and if the task can be complimented by a machine or an absolute need of the human is needed. An initial classification of tasks is achieved for humans and machines which is refined by assigning the tasks to the right resource thus balancing the process. The next stage is the engineering phase of designating the technological resources in given workspace. This is then simulated for evaluation and refinement. Finally, a semi-automated assembly cell can be achieved with human centricity.

However, measurement of the implemented solution and feedback of the users is continuously monitored for optimization of the solution. The cyclic process is based on the work of [18] [21].

3.1. Physical automation of assembly cell

Assembly work characterizes with a large variety of simple to complex physical tasks. Nevertheless, many of the tasks are repetitive. These repetitive tasks can be benefited by using human-robot collaboration. The emerging trend in production automation is towards collaborative robots or co-bots. In a collaborative environment, the tasks can be distributed based on strengths of robots and humans. The distinguishing features of collaborative robots are their safe and effective interaction with human workers and ease of deployment and operation. Productivity, ergonomics, and safety conditions are potential areas of getting benefit from collaborative robots [22][23].

As suggested by [14] the use of collaborative robots can greatly transform the role of human operators in accomplishing the physical tasks. The robots can takeover repetitive tasks demanding higher accuracy but less ergonomic complexity. Various forms and levels of human-robot interactions are presented in literature [24].

3.2. Cognitive automation of assembly cell

The operators at the assembly cells are required to acquire information from their environment and their fellow resources
(man and machines). Augmented reality (AR) is a digitized representation of digitally processed reality with digitally added virtual objects forming a real–virtual interaction. AR can help to instruct an operator of assembly instructions, supervise the assembly process or maintenance [25]. This can help to ensure process stability and predictive maintenance [26]. Horejši [25] described the potential manufacturing related benefits of AR in logistics, assembly planning, and training. The full potential of AR can be realized through Internet of Things phenomena. IoT is an internet connected network of goods and objects that can exchange data [27].

The watch alerts the operator by providing work related information and notifications at watch and vibrations.

Fig. 4. (a) Gesture control armband to teach robot (b) Wearable to receive process notifications.

4. Changing roles of humans in human centered automated assembly cells

Humans, when collaborating with technologies, might see a shift in their roles in the assembly process. Experiences have shown that automation does simply not replace human activity but rather modifies it, often in a way not intended by the automation architects thereby posing new demands of coordination from the human operators [12]. [28] has explained the roles of humans in a production system as bystander, operator, teammate, programmer or supervisor. In manual assembly cells, the operator is acting as an operator while in fully automated cells, the roles of humans are supervisor or observer.

In contemporary design process greater functions are given to the machines while the human is assigned to monitor the system for prolonged periods of time for a job for which humans were considered magnificently disqualified [29]. Human as observer becomes complacent. In this scenario the humans expect the automation to do the job for longer periods of time. Everything can work as expected however in case of an accident (and when human is needed to intervene) it will be too hard for human to handle the surprise and get back into the automation loop, to diagnose the problem and take necessary action to put the system back into functional cycle [5].

With a balanced merger of machine capabilities with human skills the humans might be working as teammate or programmers. This might require training of existing employees. This will also require that the vocational skills are updated at the institutes to accommodate the needs of changing landscape.

5. Evaluation and experimentation

Technology driven devices are selected for evaluation of assembly tasks automation. These are:

- Collaborative robot
- Augmented reality glasses
- Smart watches

For experimentation and validation, a manual assembly cell is selected from a local manufacturing company. The cell produces an electronic linear actuator used in height-adjustment desks. Fig. 6 shows the parts of the product and the experimental setup. In the actual industrial setup, the operator receives sub-assembly #1 on a conveyer from the previous station, and mounts gear-wheel #2, bush #3, ball bearing #4, back fixture #5, shall #6, gasket#7, lid #8 and mounts screws and then moves the assembly to the next station by hand.

An experimental setup was developed to test the technology enabled assembly automation scenario. The tasks identified suitable for automation were performed using a collaborative robot. The robot used in the experiment was Universal Robot UR-10.
The manual tasks can be described as physical and cognitive tasks. Mounting of gear wheel, bush, ball bearing, shall, back fixture and lid are physical tasks, while conformity to the required placement orientation is a cognitive task. Further, there are two variants for back fixture and the decision to choose the right variant is also a cognitive task. Besides, there are certain human activities where operator needs to take information from the environment. These are sensing tasks e.g. the robot, after completion of its tasks, signals the operator to pick and move the product or the breakage of a machine would signal the operator to take necessary action.

![Experimental setup](image)

**Fig. 6.** Product and experimental setup for the user-study.

For automation of physical efforts, tasks 2 to 7 are assessed to require human intelligence and dexterity while tasks 8 and 9 are assigned to the robot. The usefulness of having mechanization (HRC) can easily be evaluated in form of reduced operator’s involvement, increased productivity resulting in economic benefits.

![Productivity analysis](image)

**Fig. 7.** Productivity analysis of experimental work cell in discrete simulation.

By using the recorded cycle time from the experiment, a discrete event simulation was developed to compare manual and HRC scenario for changes in the productivity. Simulation analyses were conducted using Tecnomatix Plant Simulation for Windows version 14.2 (Siemens AG) and the results (Table 2) depicted that the use of a robot for assembly collaboration of physical tasks can increase productivity.

**Table 1. Simulation results for productivity analysis of HRC**

<table>
<thead>
<tr>
<th></th>
<th>Cycle time (s)</th>
<th>Human time (s/p)</th>
<th>Human efficiency (%)</th>
<th>OEE %</th>
<th>Per day production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>78</td>
<td>78</td>
<td>80</td>
<td>90</td>
<td>1042</td>
</tr>
<tr>
<td>HRC</td>
<td>78</td>
<td>62</td>
<td>80</td>
<td>90</td>
<td>1248</td>
</tr>
</tbody>
</table>

Cognitive tasks are automated using augmented reality glasses. The operator visualizes the assembly instructions avoiding any errors. Once the robot has completed its assigned tasks (i.e. screwing) it generates a notification to the operator and operator moves the assembly to the next station. Usefulness of cognitive automation solutions is harder to quantify and therefore qualitative user studies are considered.

Qualitative evaluations were made by the students to perform the tasks with the human-centered automation system. The students first made the tests by manual assembling where parts were randomly placed in front of them. They were instructed and were asked to perform the assembly by picking the right part. In this case, they had to think and decide to which component must be placed. During the experiment, the videos were made and were evaluated for the time spent on identifying the right parts during manual production and providing instructions with holograms in the next test. Similarly, number of times the participant picked wrong part and placed it back was counted as an error.

Participants used robot, augmented reality instructions, and smart watch separately and then in a combination to evaluate their experience (Table 2). With each experiment value adding time (VAT = time performing assembly) and non-value adding time (N-VAT (thinking or making errors)) was recorded. Additionally, number of times wrong component was picked (i.e. an error) was noted. Further, the students were asked, in form of a questionnaire, for their use experience with the devices. A similar questionnaire was asked at the manufacturing company from the operators who were working directly with the robot or coexisting in the robotic workspace.

**Table 2. Comparative analysis of manual vs Lean automation.**

<table>
<thead>
<tr>
<th></th>
<th>Manual</th>
<th>Physical + cognitive automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time (s)</td>
<td>41</td>
<td>49</td>
</tr>
<tr>
<td>VAT (s)</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>N-VAT (s)</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Productivity</td>
<td>78</td>
<td>73</td>
</tr>
<tr>
<td>Errors</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

The results from the questionnaire revealed that most new technologies are developed with the idea of hiding complexity for the end user but still are challenging for elderly workforce in the companies (Table 3). Nevertheless, the reconfiguration in these technologies is not easy for the end-users and expert knowledge is required.
6. Conclusion

As the need for agility in manufacturing paradigm is increasing the vitality of humans in production system is becoming important. The shift in mindset from human-less fully automated systems to human-centered Lean automated systems can enhance the performance and productivity. The concept of Lean automation by keeping human at the center of an automation system and utilizing the bests of humans and machines in a combination can offer to achieve high productivity especially in manual works e.g. assembly.

The results are not only visible in increased productivity but also in increasing safety, improved ergonomic conditions and human wellbeing.

References


