IDETC/CIE
International Design Engineering Technical Conferences
& Computers and Information in Engineering Conference

CONFERENCE
August 26-29, 2018

NSF / ASME Design Essay Competition 2018

Quebec City, Quebec, Canada

Graduate Category

Human-Robot Symbiosis in Manufacturing and Design

Submitted by:

Darshan Yadav

Florida Institute of Technology

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Abstract

Design and Manufacturing in 2035 will be radically different than current design and manufacturing practices. Demand of unique and personalized products is increasing more and more. In future, this will make mass manufacturing almost infeasible. Companies need to acclimatize to this change in demand as well as developing technologies. Growth of Internet of Things (IoT) and Artificial Intelligence (AI) will allow designers access to incredible amount of data along with robots that will provide them an incredible amount of control and consistent, high quality output. Manufacturing and design in future will be done “with” robots instead of “by” robots by sharing the workspace. This human-robot collaboration will enable manufacturers to produce customized products in large volumes and make changes to product design in real time based on customer feedback. This paper explores this possibility for our enterprise in order to be a pioneer and dominate the market in future by enabling our workers with human-machine collaborative environment. This paper details some of the latest advancements in this field and more importantly various challenges that we will face in this process, both as an organization and as a society, what type of employee policies we need to make in order to make this journey with them and various partnerships we should consider in order to maximize our technological progression.

Introduction

The first industrial revolution began with the invention of using steam and water to generate power. Use of electricity for mass production kick started the second industrial revolution. Driven by capitalism, the emergence of electronics and computing paved way for automation in production which resulted in the third industrial revolution. Even though not fully evolved, the fourth industrial revolution, commonly referred to as Industry 4.0 has already begun with widespread use of robotics and introduction of Artificial Intelligence (AI) in companies such as Google, Facebook, Amazon, etc.

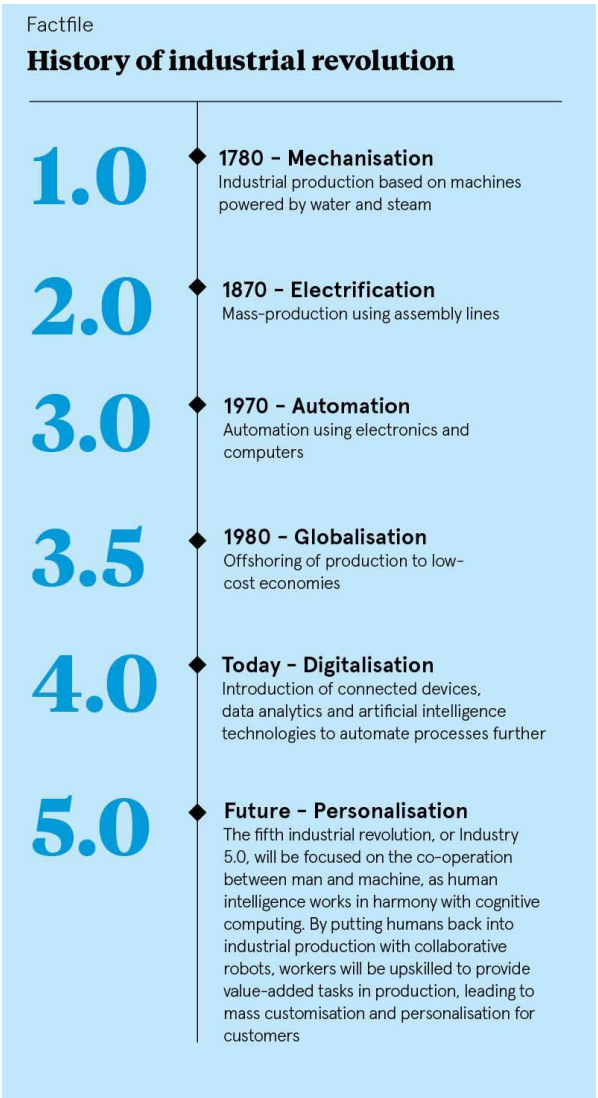

Figure 1 Timeline of Industrial Revolutions [1]

From an industrial stand point, these technological advances have propelled production to reach unseen plateaus. Manufacturers worldwide are transforming their facilities to “lights out factories” to enable themselves for higher production rates and higher quality products. Having robots in the assembly line helps manufacturers eliminate inconsistencies in production arising due to human factors such as wear, lack of concentration, volatile motivation/ effort, different skill sets, etc. Despite all the upsides of Industry 4.0, it has drawn significant public backlash for one major drawback: robots have

replaced both unskilled and to some extent skilled labor on the factory floors. This has resulted in a significant number of workers losing their sole source of income. Based on the trends, it isn't far fetched to imaging that robots will completely replace humans in most industries and we haven't even factored in the emergence of artificial intelligence. Many experts believe that if not handled extremely carefully the human-robot relationship may become similar to "Terminator" or "Ultron". Elon Musk was quoted saying "I have exposure to the most cutting-edge AI, and I think people should be really concerned by it. AI is a fundamental risk to the existence of human civilization in a way that car accidents, airplane crashes, faulty drugs or bad food were not — they were harmful to a set of individuals within society, of course, but they were not harmful to society as a whole." [2].

Figure 2 UR10 robot assisting a skilled human worker resulted in 50% more efficiency

However, there are also a lot of visionaries such as founder and Chief Technology Officer of Universal Robots, Esben Østergaard, who have a different idea for Industry 5.0 and a more optimistic view of the future. It is widely accepted that in future, robots will be able to do everything a human could possibly do and do it better. Despite the robots already "taking over" a lot of jobs in manufacturing operations in recent years, a different global consumer market of personalized goods and products that require special "human touch" is now emerging [3]. This market is not just for hand crafted items but for items and goods that require use of state of the art manufacturing techniques. Industry 5.0 will not replace humans with robots rather, it will redefine the way we utilize cognitive computing and human personality[4]. According to Esben Østergaard, this idea of Industry 5.0 will be realized due to high demand of individualization in mass production. Using robots to assist human labor also allows for increased efficiency and performance of both the worker and robot. To back this claim, Mercedes has already anticipated this change in their consumer base and have adapted their production line. Mercedes' factory in Sindelfingen, Germany now has significantly more space for human workers, allowing them to facilitate customization in the assembly line [5]. Similarly, a Paradigm Electronics, a Toronto based high-end loudspeaker manufacturer, utilized robotic arms to polish the speaker cabs to a

high luster sheen. After introducing a human worker to the operation line, they have achieved a 50% increase in efficiency.

Human-Robot Collaboration

Industry 5.0 will finally allow the manufacturers to close the design loop. For example, if you are an automobile manufacturer trying to design the next generation vehicle, you are constrained by current raw materials and manufacturing capabilities. The amount of data and its utilization in service as well as its utilization in design process is also limited currently (although this will increase with advancements in Internet of Things(IoT) and AI). With almost complete automation of manufacturing process in Industry 5.0, designers will have real time data coming from field of use and will be able to make "on the fly" improvements in design to increase performance of certain components. Rolls-Royce's business model in the last ten years has flipped from selling engines to now having 50 per cent of its revenue from providing services to the engine. They can do that because they understand the design of failure of that engine. They know what the quality process is of that engine and they know how they want that engine to perform. Wherever a Rolls-Royce or GE engine is in the world, they know how fast it is, how hot is it, its altitude and where it is in its performance lifecycle compared to where it's supposed to be as per its design capability.

According Dr. Phill Cartwright, Chief Technology Officer at High Value Manufacturing Catapult, if we are able to integrate data from the field, manufacturing processes and the design, it will minimize the need of human interaction in the manufacturing but will allow them to be involved in how the product is used by its consumers and its design with a larger impact.

Figure 3 Human-Machine Cooperation(HMC) and use of robotics in other industries

Cooperative assistance systems are now rapidly gaining pace with the advancements in data acquisition and data processing allowing a deeper and multiple layer of interaction between humans and machines. Example of such collaboration can already be observed in transportation and manufacturing industries. Human-Machine Cooperation is simply a working relationship between humans and machines where there is a shared authority in dynamic situations between associated member (humans and machines) [6]. A detailed definition was given by Hoc: "*Two agents are in a cooperative situation if they meet two minimal conditions. (1) Each one strives towards goals and can interfere with the other on goals, resources, procedures, etc. (2) Each one tries to manage the interference to facilitate the individual activities and/or the common task when it exists. The symmetric nature of this definition can be only partly satisfied"* [7].

Cobots in Industry

The term "cobot"-conflation of *collaboration* and *robot*- was introduced during the last decade of 20th century in industry practice. One key difference between robots and cobots is that robots are designed to perform their desired tasks in restricted areas such as welding, etc. This is done mostly to avoid any harm to human workers in case of some malfunction or other safety issues. Cobots on the other hand are more intelligent. They are designed to share the workspace with human workers and assist them in human operations [8]. A key function of the cobots is to help human worker(s) with physical and cognitive loading while contributing to improved safety, quality and productivity [9]. According to Occupational Safety and Health Department of the US Department of Labor, at least 30% of European manufacturing workers suffer from lower back pain which leads to major social and economical costs at later stages.

Figure 4 Human worker and cobot sharing a work-space

Advantages of Cobots

Besides providing a safer work environment and operating conditions for human workers, cobots have other advantages over having only human workers or robots [10].

- Increased human and robot efficiency: Since the human operator and the robot work in the same space, the work piece does not have to leave that space before all the operations are completed. This helps reducing operation time, cost and floor space. According to an MIT research done at a BMW facility, a human-cobot collaborative team was able to reduce 85% of idle time compared to teams of either humans or robots alone.

- Applicable to low volume, high customization market: Because of the complexity of the programming, initial and setup required for traditional robots in industry, it is not feasible to use robots in low volume production. However, the versatility of programs, intuitiveness of the operating software and flexibility of a cobot system makes it a viable option for constantly changing product line.
- Flexibility in Human Work Environment: Cobots do not require a separate working section or protective barriers to ensure safety of human workers. In fact, as mentioned earlier, it is incredibly easy to deploy new robots, change layout or even the operation of cobots allowing a lot more freedom for human workers in terms of having a preferred work space. Their relatively small size also helps their mobility which occupies significantly low floorspace.

All these benefits make cobots more and more desirable over robots as the technology gets refined over the next few years. Currently, the cobot sales only contribute to 5% of robot market. By 2020, the market for collaborative robots is expected to be worth $3.1 billion [11]. These numbers just signify how much progress there is to be made in this field and how much potential this new working system has in the industry.

Future Factories

ROBO-PARTNER focuses on delivering next generation solutions to different life cycles operations such as Design, Planning, Commissioning and Execution of production systems. They predict the future assembly operations will combine human capabilities, intelligence and skills with robot strength, speed, consistency and precision. The future manufacturing facility layout will be robot centric in a sense that, all the operations will be performed by the robots with a varying degree of human interaction at different work spaces.

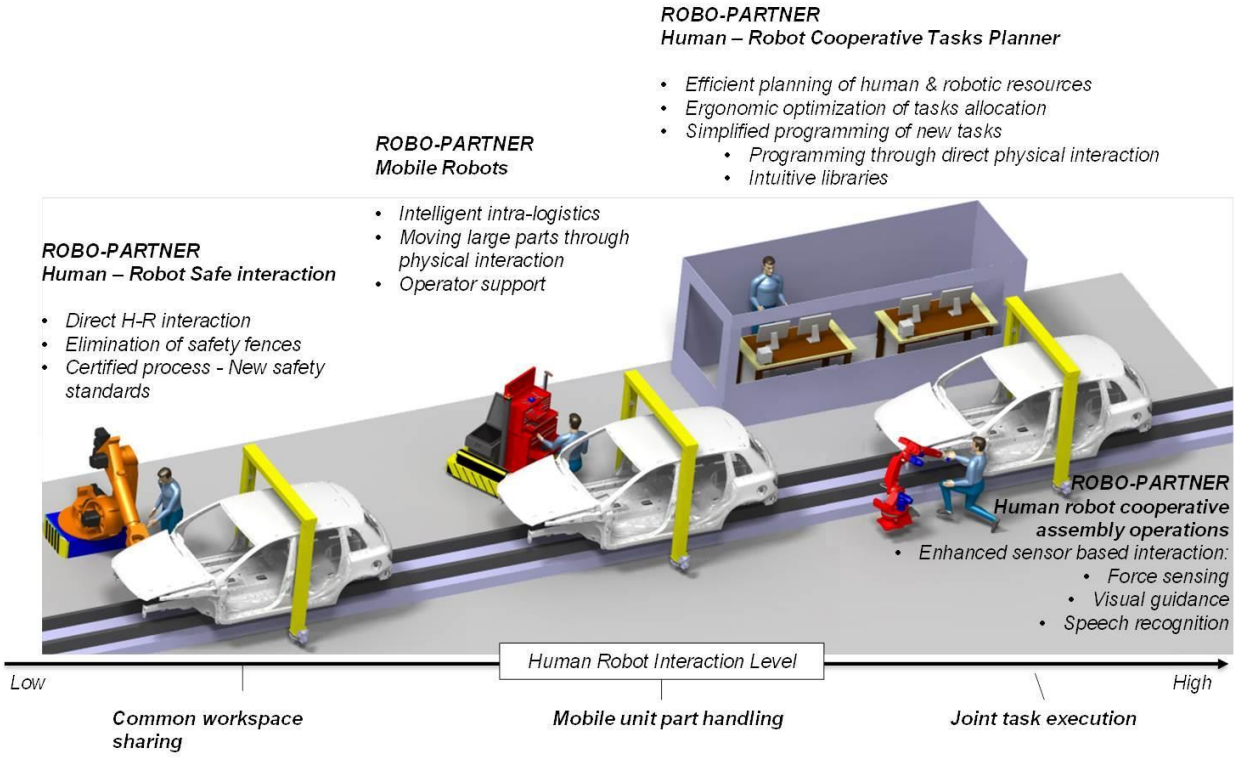

Figure 5 ROBO-PARTNER Assembly Architecture

The factories in future with cobots will focus on the following [12]:

- Development of highly intuitive interfaces for safe human-robot cooperation during assembly with the help of sensors, visual servo, speech recognition and advanced control algorithms
- Development of advanced safety strategies and equipment allowing fenceless human robot assembly cells
- Introduction of robust methods and software tools for determining the optimal planning of assembly/disassembly operations using a multicriteria, simulation enabled approach
- Adaption of simplified robot programming using demonstration and robot instruction libraries
- Introduction of mobile robots acting as assistants to the human operators
- Development of more flexible integration and communication architecture by utilizing a distributed computing model

Looking Forward

We as a company need to adapt to the latest technological developments and consumer demands if we are to succeed in future. While making plans for 2035-almost two decades in future- we also should be able to anticipate the technology and demands while carefully considering the importance of our contribution to the society. We need to be open to change in these plans as well should the need arise. In order to be equipped to dominate the market in 2035 we need to start addressing the challenges we will face while getting there. Some of these challenges need to be resolved within the organization while some bigger challenges need to be tackled on a much larger scale by everyone as a responsible society. If we are to make significant technological advancements without risking a technological apocalypse we need to work together in partnership with the community (educational institutes, other corporations, government, etc.) rather than working in silos. In order to be successful, we need to successfully counter three different types/levels of challenges: (1) Organizational Challenges, (2) Educational Challenges and (3) Societal Challenges.

If we want to establish out company as a benchmark and a true leader in the industry we must focus on all these challenges in *Figure 6* as a one big challenge rather than focus on some and must not ignore the importance of any of the issues. Now obviously some challenges are more complex than other and will require significantly more resources and that is why it is important to be clear in the vision and mission of the company. The company needs to prioritize the areas that need immediate attention and focus on others as and when needed. We should keep in mind that these are only some of the challenges we will face, we need to accept that as we make more progress we may face even bigger challenges.

Adaptation in Education of Workforce

One key area of focus that needs to be addressed quickly however is education and training of future work force. We need to realize that the workforce required for a successful human-machine collaborative environment will need fundamentally different skill sets compared to what our current education system equips them for. It is also quintessential the we recognize all the organization human factors and consider the effects of these technological changes on our current employees before we make big changes in the corporation[13].

- The current education for human workers in production is mostly manufacturing technique related where workers work on their own or with their colleagues. We need to provide them with a platform where they can learn how to work with different machines.
- Robotics currently is case specific. i.e. they are designed to work for a specific purpose in a particular setup and location. Cobots on the other hand will be more modular and will allow workers with more freedom as to what to make and where to make but less control on how to make as manufacturing will be almost completely automated.

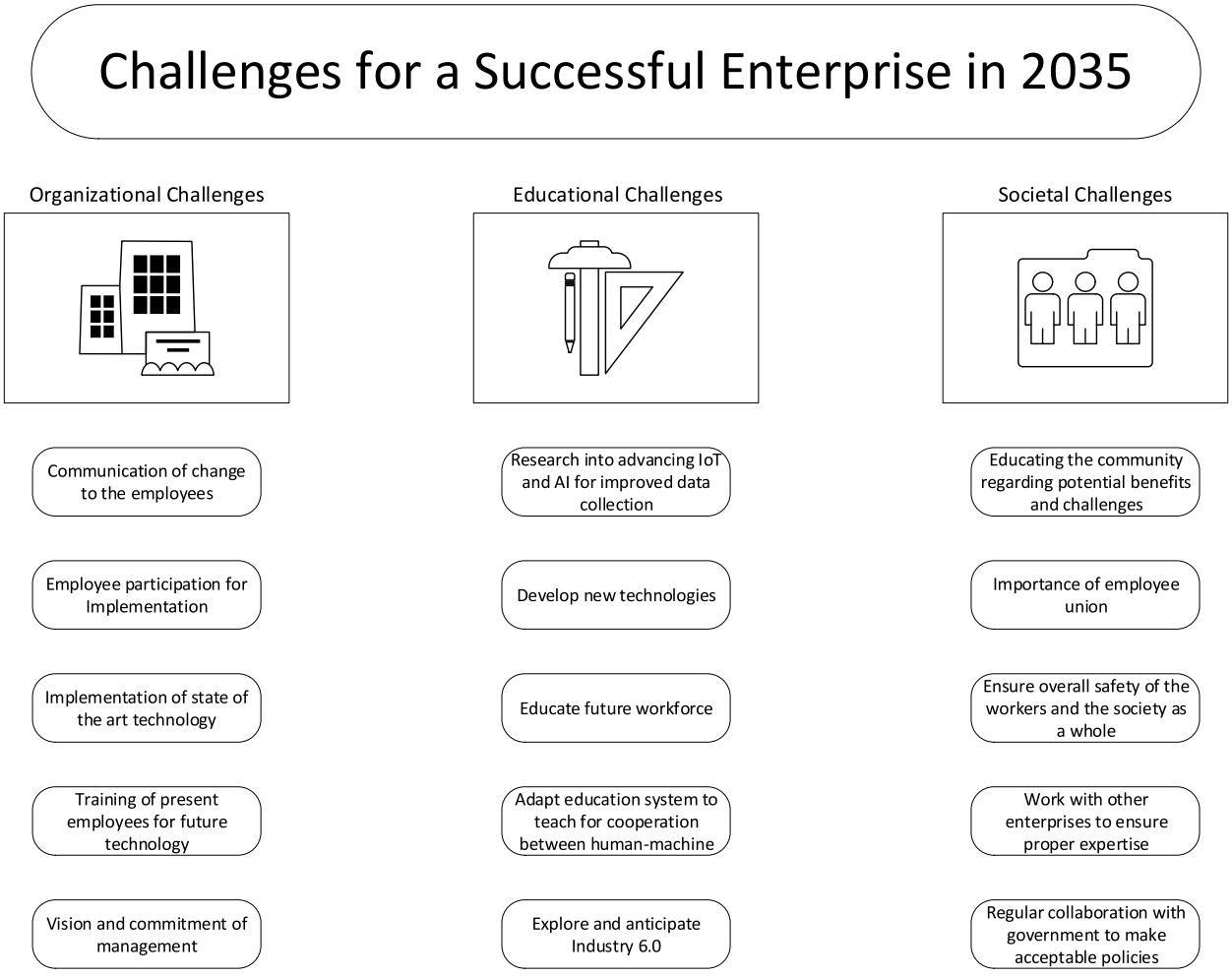

Figure 6 Challenges in 2035

- The workers will rather require a solid understanding of the design process and how to make sense of and integrate real time data into design of new and modified products. It is expected that the cobots will be able to learn operations from human co-workers and will have a sufficiently wide library support to adapt to different operation sequences and manufacturing techniques. This will require the workers to have a thorough understanding of not just the designing of the product but also concepts such as Design for Manufacturing (DfM), Design for Assembly (DfA), Design for Disassembly (DfD), etc. as well as different types of manufacturing techniques.

In order to achieve these goals, we need to form partnerships with educational institutions and other corporations to not just advance the technological development in future but also how to keep the workforce up to date with latest advancements and involve them in future evolution. In the coming section, some potential partners from both the industry and academia are discussed and why they would be suitable to our company.

Academic and Corporate Partnership

As mentioned before, the company needs to partner itself with other corporations and educational institutes in order to not just have a sustainable future but also to catch up with our competitors. It is paramount that we recognize our future potential partners as quickly as possible in order to bridge the knowledge gap that we currently have. Below are some of the potential partners we should consider based on their current research advancements and vision for the future.

Table 1 Potential Partnerships

Industrial Partners	Academic Partners
ROBO-PARTNER	Dr. Henrik I. Christensen, Robotics and Intelligent Machines @ Georgia Institute of Technology
Universal Robots	Dr. Siddhartha S. Srinivasa, Personal Robotics Lab, University of Washington
Groupe PSA, Peugeot--Citroën	Dr. Julie Shah, Interactive Robotics Group, Massachusetts Institute of Technology
KUKA Robotics	Dr. Stefanos Nikolaidis, University of Southern California
Rethink Robots	Dr. Sarah Fletcher, Cranfield University

While it is recommended that the company try to pursue partnerships with all the organizations mentioned in *Table 1*, it is recommended that we focus the most on following two partnerships. (1) Interactive Robotics Group @ MIT and (2) Groupe PSA. The research group @ MIT is focusing their research on cobot behavior based on different types of interaction by different human subjects. At present all cobots have a singular human co-worker. The advancements in this area could help us in the long run with merging of workspace between multiple different human workers and multiple robots [14].

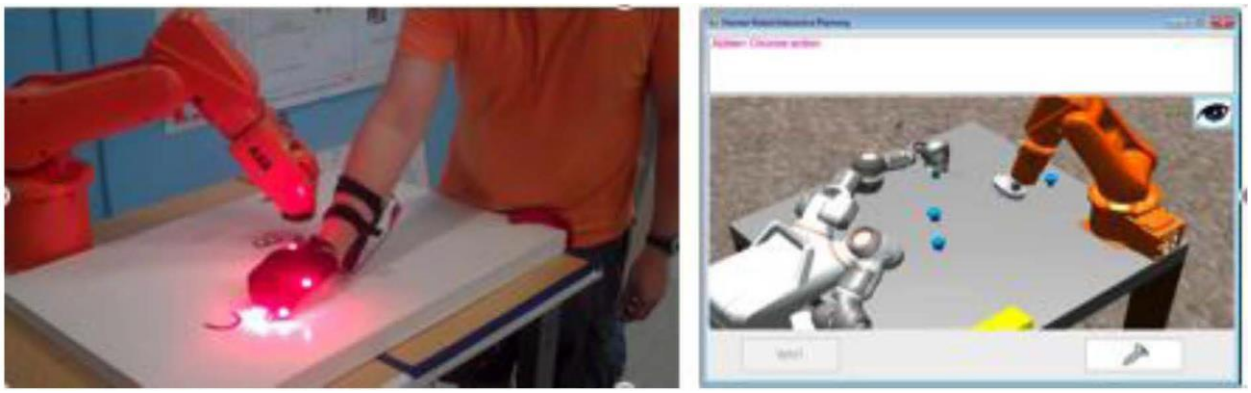

Figure 7 (Left) Human-robot joint task execution, (Right) RobotStudio simulation environment for training the robot

All other corporations listed in *Table 1* specialize in robotics while PSA traditionally has been in manufacturing business just like us. Other robotics companies will most likely treat us as a client while PSA could provide us with invaluable insights regarding the challenges they faced (both technological and with employees) while changing their own technology. They have been considering replacing the manual assembly operation of a Rzeppa homokinetic joint with a human-robot collaborative assembly

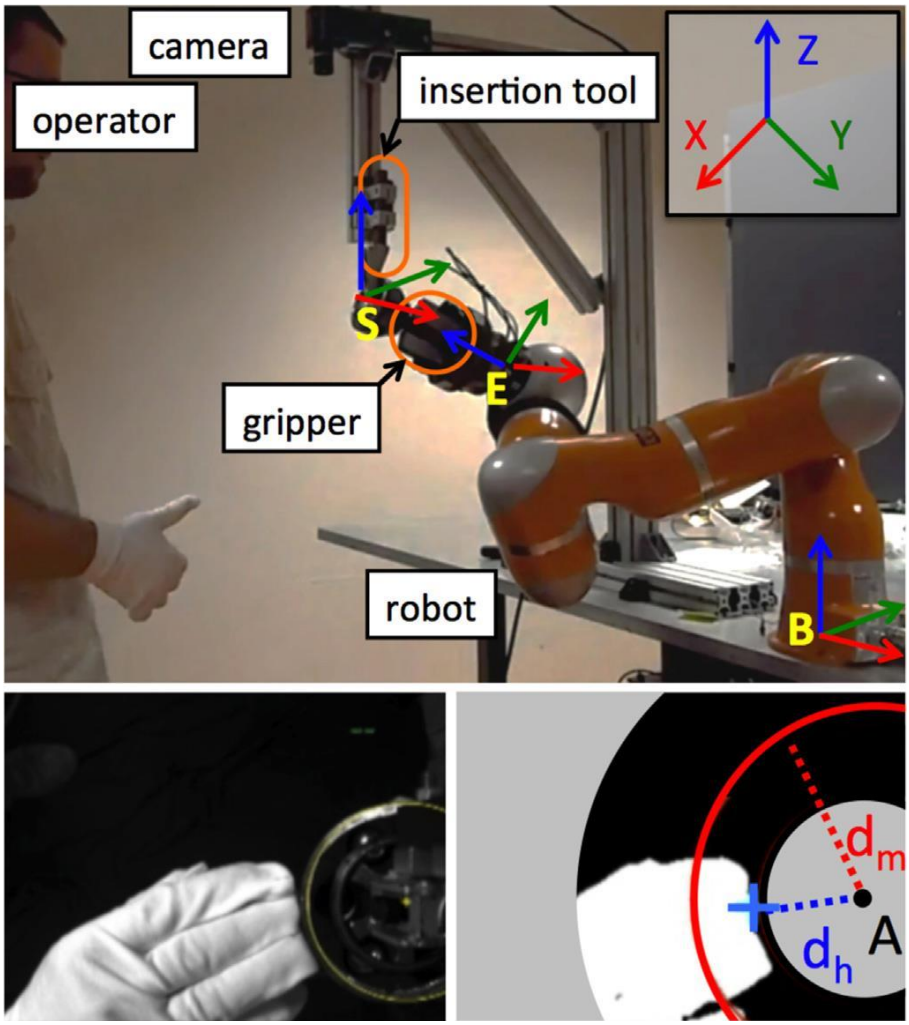

Figure 8 Setup for Rzeppa joint assembly cobot with insertion tool support(S), end effector(E) and robot base(B)

line to prevent their workers suffering from severe back pain. While analyzing the cobot system, they observed that the operator load was reduced by 60% and that the setup was actually compatible with the required safety standards and could be deployed in practice after proper certifications [9].

Closing Thoughts

Adjusting to the changing needs of consumer market and technological breakthroughs in data collection and robotics will put our organization at the forefront in research and implementation of state of the art technology in future. Integrating cobots in our manufacturing facilities will not only allow us to constantly improve and customize our products based on customer needs in future but it will also make it easier change the product line without worrying too much about setup cost for the new product line.

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