Research Article

Balancing Assembly Line Using Collaborative Robots in Modern Manufacturing Industry under Improvements of Efficiency and Ergonomics Study

[1] Yuvethieka Sri G V, [1]Gopika V, [2]Dhiventhra S, [3]Balaji Ramachandran

[1]Department of Computer Science and Engineering, Vivekanandha College of Engineering for Women, Tiruchengode

[2]Department of Electronics Communication Engineering, Vivekanandha College of Engineering for Women, Tiruchengode

[3]Centre of Research & Development, NoobTron Private Limited, India

Mail Id: sridharabalaa@gmail.com

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Abstract:

This era is utilizing technology as a tool of efficiency. It is unvarying in the industries that there is always a chance of occurrence of human error and the time consumption for the process is high. This greatly decreases the efficiency of the system. Also, an industry for the most part undergoes repetitive tasks. Humans when allotted to repetitive tasks are prone to heath and psychiatric related issues. In such cases, implementation of "Collaborative-Robots (Cobots)" assists in increasing efficiency as they have high precision and comparatively low time consumption. In addition, cobots can be specified with tasks to supplement human endeavors and aid in an ergonomic environment. Assembling various parts of the product in a sequence plays a key role in manufacturing. This paper focuses on the optimization of cobots in the assembly lines by task specification, invulnerability resoluteness for the integrated working, on-the-fly surveillance of products and guides the future industries to develop efficient industrial automation.

Keywords: Assembly line, Cobots, Ergonomics, Efficiency, Industrial4.0, Automation, Human-Robot Collaborations.

1 Introduction:

The lives of humans are facing day-to-day changes in technology. The changes begin since the industrial revolutions started from water and steam system, electrical systems, electronic systems, and now automation. These drastic changes are meant to increase the rate of production, decrease the cost of operators[1], and increases the ergonomic environment for the employees. This industrial revolution 4.0 (IR 4.0) is based on the integration of automated work[2] along with manual work that includes technologies like Internet of Things(IoT), Artificial Intelligence (AI), Augmented; Virtual and Mixed Realities(AR, VR, and MR), Cyber-Physical System(CPS)[3-5] and expecting more to be implemented. These technologies are used in collaborative robots (Cobots) to supplement tasks that are hazardous, difficult, bored and dangerous to humans. Unlike robots, cobots increase the probability of collaboration triumph as they offer high flexibility; productivity; safety; and versatility[6] than the traditional industrial robots. Cobots are user-friendly as they are equipped with active and passive safety features. They are built with light-weighted and round-edged materials[7] to avoid injury to the employees at the time of the collision. They are also embedded with sensors and other software packages to detect the presence of humans accordingly. Other safety mechanisms can also be implemented for collaborating cobots next to humans in the assembly line tasks. Unlike humans, cobots can work all-time without feeling fatigued or discomfort[4,8]. Thus, employing cobots for highly repetitive and tedious tasks assist in increased profit and are capable to meet the demand in the market[9]. Cobots also have the capacity of learning quickly and their teaching does not require a professional trainer. They can be trained just by moving their arms to a new position. Implementation of cobots not only increases the physical efficiency (ergonomics) of humans by supporting them in menial tasks but also increases the efficiency of production by increasing quality; uniformity; manufacturing speed, with reduced errors and wastages[10]. Some of the biggest challenges in employing cobots fall under cost, tasks, and maintenance. In ease, cobots do not require much concentration in monitoring them[11] as they are already embedded with enough safety precautions and while concerning cost, cobots are cost-efficient than conventional robots. As the population increases, there is an increase in the demand for a product concurrently. So, the industries are pushed to a situation to produce optimum products in a reduced time. Since cobots are the combination of human mimic with the strength and speed of robots, they bring the most efficient process of manufacturing while they are deployed in the assembly line [12]. This research is made to study collaboration in a modern manufacturing industry. The following sections include the safety mechanisms to be embedded in the cobots, teaching patterns of cobots, the contribution of humans and cobots in the collaboration along with the task allocation, and finally, describe the efficiency of the process.

2. Literature Survey:

2.1 Robots versus Cobots:

A robot is a programmable, self-mastery device that is usually put into action as an alternate for employees. As mentioned by Marek vagas et al., robots are gigantic, hefty, inflexible, application-specific, and possess electronic, electrical, and mechanical units[1]. They are often aimed at handling an intricate course of action that is strenuous and menacing. They perpetually own a separate workspace away from the human workspace.

A collaborative robot [Cobot] acts as a support to humans, assisting in 3D (Dirty, Dangerous, Dull) tasks. F. Sherwani et al., and others mention that cobots are light-weighted, flexible, easy to handle, and can be used for diverse tasks. Instead of vacating employees, they aid them by contributing towards the development of an ergonomic environment, reduces operating cost, increases the rate of return of investment. They have the potentials to share the workspace along with humans [1][2].

Table 1 Difference between Robots and Cobots

S. No	ROBOTS	COBOTS
1.	Work as an alternative to humans and eliminates their job.	Works along with humans and eliminates difficulties to them.
2.	Programming and re-programming are complex tasks as it has to be changed in the backend program.	Programming and re-programming are very easy as they are capable of learning and can be reprogrammed just by moving in a particular path.
3.	It requires Safety blockades or a Separate workspace.	Doesn’t require any safety blockades and can share the workspace with humans.
4.	Requires huge investment and the rate of investment return is slower.	Less investment in comparison to robots and the rate of investment return is faster.
5.	Easily handle heavier and larger materials. They are not flexible.	Not much efficient to handle heavy materials like robots. They are flexible.
6.	Repeats the same tasks all the time.	Can be changed for multiple tasks.

2.2 Programming Cobots:

This paper identifies some features that include cobot programming particularly required for sequential Human-Robot Collaboration (HRC) scenarios.Programsare important to make cobots understand the instruction, conditions, and actions that are aimed towards the collaborative goal.

Operators are directly and indirectly involved in the change of actions of a cobot. The cobots has to be programmed as it can be allotted to a work in a separate workspace as well as in the collaborated workspace.

Shirine El Zaatari et al., explained that there are two types of programming:

⇨ ***Offline programming:***The operator embeds dynamic program into the cobot to incorporate the task. It is similar to manual programming wherein the codes are embedded in graphical or textual form of codes.

⇨ ***Online programming:*** The operator makes some changes explicitly to the cobot in case of collision. It is similar to automatic programming wherein humans have influence on the code by means of gestures.

The importance of cobotsprogramming is to improve features particularly communication (both verbal and non-verbal), learning, and optimization. User Interface (UI) is the most differentiating feature between cobots and robots. It includes cobot teaching pendant, icon-based programming, CAD-based programming and task-based programming.

El Zaatari et al. have investigated optimization techniques in the process of products inassembly lines of the manufacturing unit in human-robot collaborative industry[3]. Learningincludes methods like recognition, demonstration, trial and error, data training and acquiring feedback.Ali et al, have discussed that the main part of the learning is from off-line programmer and is by method called Learning from Demonstration (Lfd).It is a more popular method in human-robot collaboration used for shifting human knowledge about a task using data from human demonstration to the nonlinear system cobots[4].

2.2.1 Cobot Teaching Pendant:-

Shirine et al., describes teaching pendants as the easiest way to utilize since they are built-in with cobots. The programming done by specifying the routing point [5]. However, the Robot teaching pendant's surface-level efficiency is limited, there is no action plan flexibility and also there is no human awareness[3].Cobots including Universal Robot (UR), ABB's YuMi are trained using this technique.

2.2.2 Icon-based Programming:

Hader et al.mentioned that,there are a series of command in the form of iconsin this type of programmingand the cobots are trained according to that. Each and every movement of the cobots are trained using the icons[5].Icon based programming looks simply but it is crucial to debug, manage and alter[3].

2.2.3 CAD-based Programming:

CAD-based programming (Computer Aided Design) involves training the cobots with 3-D graphics problems that makes use of software namely CoppeliaSim, Visual Components, V-REP, Robot studio, Autodesk and so on. This technique is chosen only for mass production. Thus, this method does not fit for the production of batch cobots used in HRC [5]. This programming technique might be cumbersome if there is a change in workspace design.Lucasde Azevedo et al. used CAD to create connector, an element that connects UR3 robot to Human arm[6].

2.2.4 Task-based programming:

Task-based programming is split into computation tasks. It allows programming to be fine-grained[3]. Each single movements and motions are taken into an account. Cobots are programmed as they can be employed only for a variety of task aimed at the manufacturing [5].

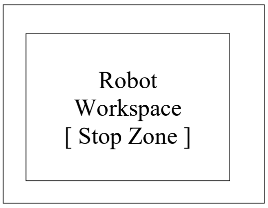
2.3 Collaborative Safety measures:

Amezua Hormaza et al. mentioned that ABB's YuMi robot that is introduced in 2015 was the first genuine cobot that is used for successful collaboration[7]. Marek vagas et al., stated that according to ISO/TS 15066, 29 parts of the human body are most prone to injury during the collaboration with robots[1]. There must inevitably be a few precautions to work in a collaborative workspace with robots. As prior mentioned in [1][2][3], there are four methods that aid in prevention of injuries leading to a safer working environment for the human workers in the manufacturing units. They are Stop monitoring, Speed and Separation Monitoring, Power and Force Limitation, and Hand guiding.
Leonardo Scimmi et al. implemented collision avoidance to make alternative trajectories in the case of human intervention in the collaborative work zone[4]. The motion of humans is tracked by sensors (here it is two Microsoft Kinect v2 Sensors) to improve the resolution of vision than traditional camera. In addition, he used three computers, a router, and a UR3 collaborative robot that is equipped with a gripper. Computers are connected via TCP and the sensors are placed 1.5 m apart from the human. Two computers collect data from the Kinect sensors and the third computer is meant to control the robot. He split up the working area into three divisions like piking, assembling, and collaborating areas. The robot is assigned to pick items and palletize them in the human operating zone. The data obtained from the sensor are given as the input to the collision avoidance algorithm and resultant velocity (sum of attractive velocity and repulsive velocity) is the output of the same. Also, he used the “kunnsearch algorithm” to evaluate the distance between humans and robots[8].
Marek vagas used two Microsoft Kinect v2 sensors for monitoring the movements of the operator and the data collected from the sensors are used in the collision avoidance algorithm. He used UR3 robots for collaboration, laser scanners as safety equipment, and also he had an operator to monitor the overall process [1].

2.3.1 Stop Monitoring:

In this practice, the cobots are allotted a workspace and they work alone for the most part. These cobots working in their workspace relinquish the work if the employee pops into their workspace and waits for the employee to finish off his work and get out of their workspace.Once, the employee left, the cobots resume their task. As there is no movement of the cobots during the intervention of an employee in the workspace, the employee is completely safe. The disadvantage in this practice is that, whenever an employee pops in, the works of the cobots are completely stopped till the employee leaves the workspace. The workspace is designed as shown in Figure1.

Figure 1: Stop Monitoring Workspace

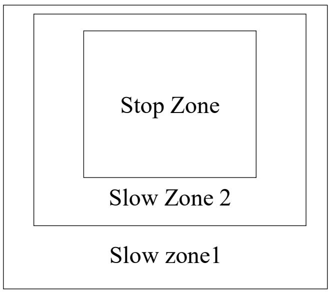


2.3.2 Speed and Separation Monitoring:

This is also a kind of stop monitoring with some contrast. In this practice, the cobots workspace is split into zones. The pace of cobot is gradually reduced in case the employee crosses each zone. If the employee reaches the last zone, the cobot relinquishes the work and gradually resumes the work once the employee leaves the nearest zone. The advantage of this method is, the cobots never stop their work all of a sudden. Yet there is a halt in the process. If the halt should be avoided, an alternate collision-free path can be allotted to the cobot task[3]with the help of signals from the sensors embedded in the cobot. But this approach requires a human track system to ensure if the alternate path is intervention-free[1].
Scimmi et al. proposed two possible approaches: Global and Local trajectory changes. Global trajectory change requires the entire geometry of the industry and the position of humans in the redirected path to pursue smooth movement of cobots whereas, local path trajectory change can give optimal path but the guarantee of reaching the destination is doubtful [8].. The workspace is split into zones as shown in Figure 2.

E. Kim, et al. experimented the SSM collaborative operation method to ensure security for the operator from collision by continuously monitoring the movements of humans and robots. He used a sensor related to safety to continuously monitor the distance between the operator and the cobot[9].

Figure 2 Speed and Separation Monitoring Workspace



2.3.3 Power and Force Limiting:

In this practice, the robots are designed in a way that they are operated in the force that is adorable by humans. Thus, there is no lag inthe work of cobots as there is no factor for stopping their work. Humans can continue their work without disturbing the flow of cobots. P. Aivaliotis, et al states that, vision system can be embedded in the cobots to detect the unexpected collision of human near the robotic arm in prior[10]. Most of the time, the cobots used in the shared workspace are manipulators (robotic arms), having only a few possible movements. The advantage of this method is that there is no requirement for safety sensors[11], other devices, or a separated workspace since the robotic arm surface is rubber framed and also has an advanced sensor system to sensate the external forces near the arm. It makes cobots harmless to humans[1] .

2.3.4 Hand Guiding:

The cobots are trained in such a way to change their path in case of human intervention. This method is efficient for complex tasks. This is most prominently used in the pick and palletize applications as the cobots can be trained easily by moving their arm. Though it is much easier, there exists a need for a sensor to avoid head injury to the collaborated employee[1]. Malik et al. mentioned that it is mandatory to change the trajectory of the cobot in chance of collision[12]. Thus, this mechanism greatly aid in fast changing trajectory for human safety.

2.4 Collaborative Task Allocation:

Collaboration is generally expounded as the single-minded interplay among humans and robots involved in the same task and same workspace[3]. If the robots can recognize and interpret in an elucidate manner then the collaboration is said to be an adequate collaboration. The probability of triumphal collaboration is accomplished by ensuring a safe working environment with increased ergonomics and efficiency. These are achieved inimitably if Cobots are deployed with the proper framework and tasks. It is indispensable to train the employees to learn to work with cobots before assigning them to a collaborative task. For that cause, training them requires a part of the time, it might affect the industrial working hours. As an initial step, employees could be practiced through a Virtual environment before dealing with a factual one. This feeds them enough confidence to work alongside the cobots without affecting the working hours.

Amezua Hormaza et al. suggests that mostly, late-job (after working hours) training could be the best method to train employeesin between the virtual and factual collaboration. This not only makes the collaboration easier but also makes the movements of cobots familiar to the employees[7].

The classical collaboration approach by Fitts states that Collaboration should be made in a way in particular, the tasks that can be automated are all given to cobots while the rest of the tasks are assigned to humans. This approach made cobots a superior to humans. Opposing this approach, Norman stated that, those tasks that humans are capable to workare assigned to humans while the others are assigned to cobots[13]. Many things must be taken into considerations during a collaboration that includes, different types of collaborations, various roles of humans, and task optimization. They are classified based on the Workspace (The region of collaborative work of humans and robots) and Zone (The region of movement of robots and humans to perform a task[13]. There can be different types of zones based on the work and collaboration).

2.4.1 Types of Collaborations:

Considering the workspace, zone, and interaction, Collaborations can be classified into four major types[3][13]. The task should be allotted in such a way as to reduce time and energy consumption, increase efficiency and reduce defects. They are,

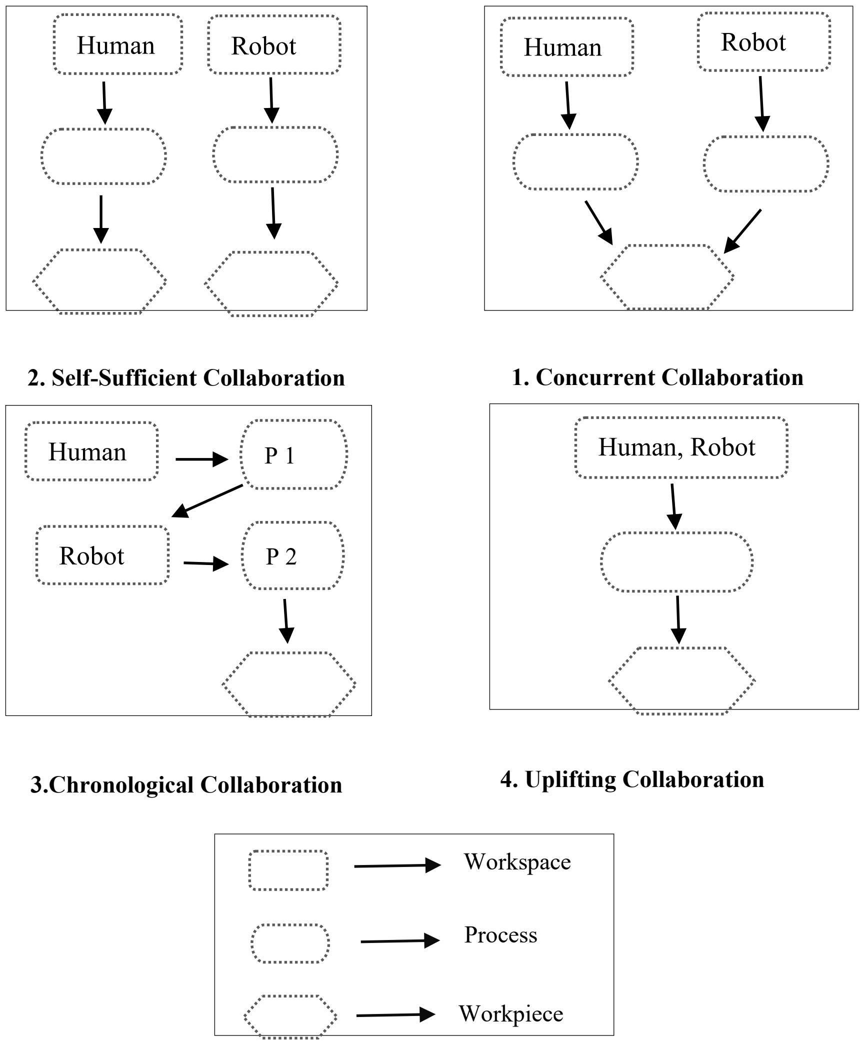
⇨ ***Self-sustaining Collaboration:*** Humans and cobots work on a separate process for doing the same workpiece. It mainly depends on safety as both have separate workspaces as in Figure 3(1)

⇨ ***Concurrent Collaboration*:** Human and Cobots work on the different processes on the same workpiece as in Figure 3(2)

⇨ ***Chronological Collaboration:*** Human and Cobots work on two different processes that are subsequent in the manufacturing of workpieces as shown in Figure 3(3) Time is a dependent factor in this collaboration.

⇨ ***Uplifting Collaboration:*** Human and Cobots alternatively work on the same process of workpiece manufacturing as shown in Figure 3(4). Here, Cobots assists human in the process interactively meanwhile improving ergonomics. Cobots have to figure out the movements of the operator. Without one, the work of others could become difficult.

Figure 3 Types of Collaborations



2.4.2 Task Allocation:

It is a general thought that collaborations with cobots lead to the unemployment of many workers. On breaking that, there are jobs that are carried out exclusively by humans during collaboration[13]. Malik et al. described those activities and it goes here: Chief (Monitors cobot), Operator (Reprograms cobot), Collaborator (Works with cobot in shared workspace), Mechanic (Change's design of cobot) and On-looker (Does task inside cobot workspace).

Cobots are more efficient than humans in performing tasks. They are employed in almost all the fields like medical (for complex surgery), painting, Assembly line automation, Humanoid robots, etc., In the aspect of industrial manufacturing, cobots are assigned with tasks like assembling, 3P (Pick, Palletize, Packing), welding, gripping, gluing and other final processes[2]. Action planning for cobots during collaboration can also be done by task networks, AND or OR graphs, STRIPS-based planners, and Markov Decision Process[11].

⇨ ***Assembling:*** The quality of the product is first defined by the proper assembling of different parts of the workpiece. If this task is allotted to cobots under the supervising of humans can increase production speed with great accuracy. Power and Force Limiting robots are much suited for this role.[3]

⇨ ***3P:*** These are the activities that require the highest precision and at the same time, these tasks consume more time and energy if handled by humans. Single armed cobots are much sufficient to perform pick and place tasks and a double-armed cobot could perform palletizing tasks easily.[14]

⇨ ***Handling:*** One of the most tedious tasks for employees is to move the finished workpiece from one unit to another unit [14]to continue further processing. This task of handling materials if automated provides an ergonomic environment. A separate path can be allotted for cobots that are performing this task.

⇨ ***Structuring:*** This section includes the process that gives the product the final look and it takes welding, soldering, polishing, gluing, grilling. These processes can either be automated using end-effector tools in robots or can be used to alert the employee before a catastrophe by using sensors integrated with computer vision.[14]

⇨ ***Inspection:***Inspecting the product is a key role in manufacturing as it raises the quality of the product[14] and also aids in profit. Cobots have high precision and if accompanied with Machine Vision, inspection becomes easier, earlier, and accurate[14].

F. Sherwani et al., used "UR16e" from universal robotics that has six degrees of freedom, 35 lbs., +/- 0.05 mm repeatability, a payload of 900mm for automating material handling, palletizing, and machine tending[2].

Karami et al. modified the FLEX HRC framework to CONC HRC. FLEX HRC allows the interaction of multiple robots, assigned to various tasks, to jointly carry out a process. He also simplified the inspection process by a demonstration that involves a human supervisor, a dual-arm cobot (here it is Baxter manipulator), and a Movable manipulator (here it is Kuka youBot). The movable manipulator picked the product (the demonstration is done with wooden pieces) that has to be inspected from the workspace and delivered to the dual-arm manipulator. The dual-arm manipulator inspects the product using vision-based inspection and palletizes the product into different boxes accordingly [16-20].

Thus, employing cobots in the assembly line with proper task allotment can increase quality; stability; productivity; profit; ergonomics, and also reduces costs and downtime[13, 21].

2.5 Efficiency and Ergonomics:-

The major factor behind Industrial 4.0 is to increase efficiency and ergonomics. It is well known that, if a process is automated the industry can achieve efficiency in all aspects including cost, time-consumption, and error. Similarly, it is mandatory to make employees work in an ergonomic environment [14]. Ergonomics is an important mechanism of reducing risk task allocation time and improve productivity production[22,23].Ana colim et al., through her investigation concluded that, assembly workers are prone to burns, stress, hematoma, cuts, ocular injuries and wrist-related musculoskeletal disorders [15].Fayomi et al., stated that the main difference between the developing nations and developed nations is ergonomics[16].

Anita, et al., deduced that collaboration if mis-managed has serious impact on efficiency and ergonomics. Also, she inferred that autonomous mode is appraised by many people and more so, autonomous decision-making robots are welcomed[17].Efficiency and ergonomic increases when cobots with human skills are employed to assist employees in physical and psychological pressure [24-26].

Thus, deploying cobots in the repetitive and burdensome tasks will lead to an increased ergonomics and efficiency.

Discussion:

- Cobots with a single camera monitoring would cause the problem of occlusion, while the usage of multiple sensors would cause data fusion[1]. Thus, separate cloud has to be maintained to store data from different sensors.
- It could be comfy while cobots could have the potential of speech recognition as they could be intuitive and cognitive, and there will not be any disrupts to communicate with them.
- Technologies like VR, MR and AR can be applied during the late-job training of collaborations.
- Also, local trajectory change can be implemented for fast-path changing operations if there exists a chance of collision.
- Speed and Stop monitoring in case of separate workspace and Power and Force Limiting methodin case of shared workspace seems to the best safety measures to be continued. Operating cobots in homokinetic velocity [1]can add additional debonair to the industries.
- Cobots like UR, Kuka, Fanuc, fruitcore robots, Franks Emika, Techman robot, ABB, and Drag&Bot are already tied up[5]. With further enhancements, they could be made avail for offhand practices.

4. Conclusion:

- Deploying cobots is an essential one while it comes to increased quality of the product, increased manufacturing count of the product, reduced number of defects, reduced processing time, increased ergonomic environment, and other crucial outcomes. At the same time, humans need not panic about losing their job as these cobots are meant to reduce their strenuous tasks to an easier one.
- The safety measures and the training method explained serves to be a better way to guarantee a safe and hazardless workplace and the employee could get rid of strenuous tasks.
- Thus, modern manufacturing industries could comply with the demands in society if they could deploy cobots in an effective paradigm.
- Use of technologies like AR (for training collaborative environment), Big data (to store the data from different monitoring sensors), AI (to train the cobots) can add additional features in the manufacturing units.
- Cobots developed using 3D printing aids in minimal cost in the production of cobots. Further enhancement in cobots could be the development of speech recognising cobots with the capacity of multi-tasking.

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