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Review Article

Introductory Guide to Collaborative Robots

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ABSTRACT

Collaborative robots are recently recreated based on industrial robots in order to work safely alongside human workers. Cobot implementation can be simpler and faster than the robots used commonly in industries, which means less time taken for robot training and integration, and a quick return on investment. This paper introduces a guide for how cobots are more easily incorporated into the work area in production while assisting workers' activities and a cobot service ecosystem that has been developed to helps small-and-medium-sized manufacturing companies.

Keywords: Collaborative robot; Human workers; Automation; Manufacturing

INTRODUCTION

Collaborative robots, or cobots, have been widely used as an assistant who helps human workers rather than replacing them. Cobots, like the robots used commonly in industries, have performed monotonous, repetitive, unsafe or unhealthful work of moving parts and operating machines so humans can do what they're very skillful at such as directing and controlling operations [1]. There are more and more cobots on the market these days. The assembly application, particularly, is likely to continue the growth of its market share because of demand from labor-intensive industries such as automotive, electronics, and machinery and equipment. The growth is mainly due to high Return On Investment (ROI) rates, easiness to use, and the flexibility that cobots can provide. It leads to growing attractiveness from small-and-medium-sized manufacturing companies (SMM), which frequently operate in the automation-challenged high-mix/low-volume production [2].

The most severe problems that cobots are facing are the speed and payloads in which they can perform tasks, both of which are far lower than that of industrial robots. In addition, industrial robots are often integrated into more specialized systems than cobots so that they can help boost plant production remarkably. Although industrial robots have been widely used in improving manufacturing operations, their usefulness has been restricted by their complex usage, inflexibility, and especially inability to work closely with humans. As a result, the current market for collaborative robots is very active due to supporting multiple types of human-scale automation with easiness to set up and program, being capable of performing with a wide range of human activities, and being able to work safely alongside human workers [3].

Cobots will mainly replace certain low skill workers. However, it is very likely that cobots will keep assisting human workers with higher-level tasks [4]. Choosing the right type between cobots and industrial robots can unlock more efficient production and boost your future growth. It starts with understanding both the strengths and limitations of cobots.

FEATURES OF COBOTS

Understanding features of cobots is especially crucial to choose the right cobot for production lines in addition to production's specific needs. Some of the unique features of cobots are as follows:

A) Robot specification: Cobots vary from brand to brand so that understanding robot specification makes it simple to find a suitable robot. For example, cobots are generally suitable for tasks with a reach of 500-1300 mm, and moving parts that weigh less than 3-16 kg. You can screen a number of robots with those robot specifications alone. The following are the main specifications of cobots, which are shown in Figure 1.

- **Payload:** It is used to determine the weight that the cobot can lift. This is one of the critical specifications to differentiate cobots from each other. The weight capacity of each robot manipulator should consider the robot tool and the part carried. The full payload is determined as weight capacity carried by the

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robot manipulator at a certain acceleration without an emergency stop

- **Robot motion range:** The most common cobots have six axes of movement. They are similar to the configuration of a human arm and consist of a series of axes connected by rotary joints. Their axes have a limited specific scope of motion at a different speed. The number and placement of axes determine the flexibility of each model. On a typical cobot specifications table below, the joint motion ranges come in + or - degree of movement from the center base position of each axis

- **Robot motion speed:** It is one of the important criteria to match certain speed specifications for a robot application. A motion speed is represented as degrees traveled per second. The robot motion speed can be adjusted according to the task context. A safety function is related to monitoring if the robot motion speed does not exceed the specified speed limit

- **Accuracy and repeatability:** Cobots can repeat their actions while hitting the target every time. This measurable characteristic has a direct impact on the effectiveness of cobots during performing tasks. Accuracy is the measurement of the difference (i.e. the deviation) between the requested task and the obtained task. On the other hand, it is the precision with which a computed or calculated robot position can be achieved. The ability to return to an exact location, again and again, known as a robot's repeatability, can be defined as the closeness of repetition of the same task several times under the same conditions between several positions reached by cobots. The accuracy of cobots is normally worse than the repeatability of cobots. More precision-driven tasks will require higher repeatability as well

- **Reach (mm):** The reach capabilities of cobots often play a major role in deciding whether cobots are right for the application. Cobots need to be able to reach all necessary areas of the part it is working on or system that it is working in

ITEM	Indy7
DOF	6 (all revolute)
Payload	7kg
Joint Motion Range	1,2,3,4,5 : ±175deg | 6 : ±215deg
Maximum Joint Velocity	1,2,3 : 150deg/s | 4,5,6 : 180deg/s
Maximum Tool Speed	1m/s
Maximum Reach	800mm (from 2nd joint to 5th joint)
Repeatability	100µm
Weight	28kg

Figure 1: Cobot specification example.

B) Safe operation without fences: Collaborative robots allow both the operator and robot to work closely with each other by ensuring the robot will slow down and stop before a contact situation occurs. As such, cobots should guarantee workers' safety based on innovative collision detection algorithms, such as power and force limiting feature or speed and separation monitoring, etc (Figure 2).

Figure 2: Safety without fences.

C) Reprogramming for everyday use by field engineers: Most cobots are designed for easy setup within "one hour" with simple touch screen programming. They offer more intuitive direct teaching by physically moving robot joints based on real-time monitoring and limitation of joint velocities and currents during joint move programming. With such a direct teaching method, cobots can mimic a picking and placing motion similar to a human. They can be used for repetitive motions, including packaging and case packing applications. Figure 3 shows an easy-to-use teach pendant developed independently to program cobots. This makes cobots a very cost-effective and intuitive solution.

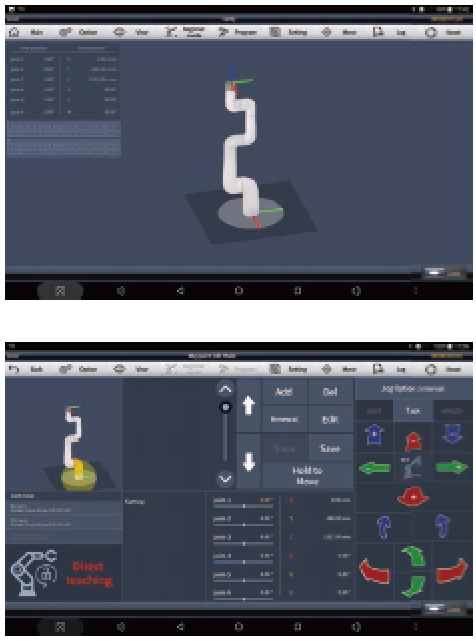

Figure 3: Easy-to-use teach pendant app.

INTRODUCTORY GUIDE TO COLLABORATIVE ROBOTS

Cobots aim for robots as smart tools, and they help to remedy insufficient labor force and guarantee workers' safe working environment. As such, they play a major role in improving workers' productivity and flexibility. How can manufacturers determine whether a cobot can be applied to their applications without help from a system integrator or other resource? The following introductory guide helps manufacturers understand key factors of cobots, which is especially important to plan economic success [5]. These are as follows (Figure 4):

- **Throughput:** A cobot typically conducts simple and routine tasks at a slower speed than that of human workers. However, they can keep performing tasks without stopping, even it can work during breaks/lunches. So, it is likely to increase productivity by reducing schedule losses. Takt time (or cycle time) is the important metric of throughput to determine a robot's speed because it means the maximum amount of time in which a product needs to be produced in order to satisfy customer demand [6]

- **Robot specifications:** During the early stages of the robot selection, robot specifications play a major role in selecting the right cobot for the industrial application that needs to be automated, such as robot size, payload capacity, repeatability, reach, and so on. The key specifications among them are axis speeds and motion ranges. They can affect cycle times and work envelopes. In some cases, multiple cobots can be needed or production layout can be changed

- **Grippers and end effectors:** An end effector is a generic term that includes all the devices that can be installed at a robot wrist. Grippers are the most common type of end effector which is attached to the robot arm to grip parts and touch machines. A gripper comes in direct contact with parts, so it's important to choose the right type of gripper for your operation. There are four types of robotic grippers: vacuum grippers, pneumatic grippers, hydraulic grippers and servo-electric grippers. Manufacturers choose grippers based on which handling application is required and the type of material in use. A suction cup is the most common type to hold parts or two-fingered gripper to pick up parts. A single and flexible end effector can be made for multiple processes, or individual tools can be used for each job. The tools available commercially can be simple and cost-effective, but custom tools might be just what you need even though they may add cost and complexity

- **Parts and presentation:** Automation of assembly of parts for products utilizes fastening or joining methods such as driving of screws, application of glue or other adhesive, welding, or other fastening applications including clips. Parts that are consistent in size and shape makes it easier to specify an end effector. Robots can be equipped with a vision system [7]. If possible, however, it had better avoiding the need for the vision system to identify the location and orientation of parts

- **Safety:** The safety of cobots should follow the international standards documented by ANSI/RIA R15.06-2012 and ISO 10218-1,2:2011, which regulate the speed and payload combination of cobots to reduce risk to the interaction of robot and workers [8,9]. In some cases, the risk assessment needs to be conducted to estimate the risk of human-cobot interaction. The risk assessment involves moving parts with sharp edges, a cutting tool, a welding torch, or a grinding wheel. After risk assessment, if significant safeguards are required, an industrial robot may be better in terms of taking advantage of its elevated capabilities [10]

- **Flexibility:** In order to constantly improve operations, industrial robots generally aim to aid low-mix high-volume production. However, at the other end of the spectrum, there are automation-challenged high-mix low volume manufacturers that differ significantly in product variety, volume, equipment, etc. The real value of cobots supports flexibility in that they can operate in high-variation/low-volume production for small manufacturers like job shops, even though cobots conduct tasks at a slower speed and payload than industrial robots. In addition, lightweight of cobots allows them to move one place to another by a rolling cart. Each time a cobot is moved, it needs to be adjusted unless it is localized to its workspace where parts and machines surrounding the cobot are where the cobot expects them to be. Reprogramming can be easily done, stored, and reloaded on a teach pendant

- **ROI (return-on-investment):** Cobots deployment is more economical than industrial robots in that they tend to be more easily learned and integrated into the workplace. It leads to less time required for integration and training and then a faster return on investment. Smaller manufacturing companies are now turning to implement cobots for applications such as machine tending. The return on investment now makes sense with easy programming without previous coding experience necessary, lower-priced robots including implementation costs, and the rising cost of human labor

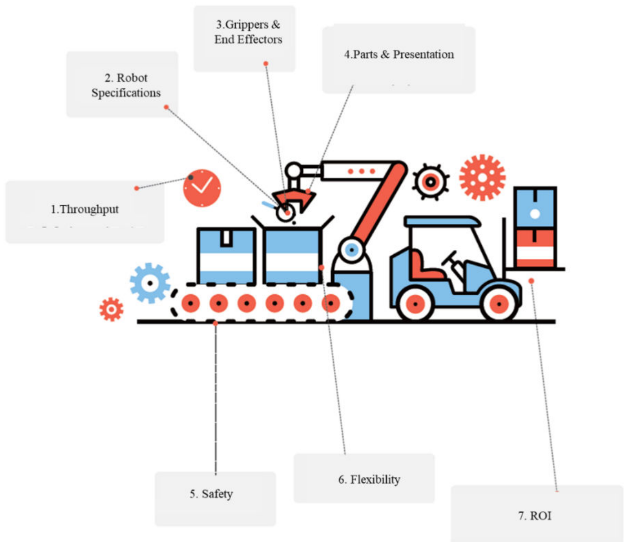

Figure 4: Seven key factors for successful implementation of collaboration robots.

COBOT SERVICE PROGRAM

A cobot service ecosystem has been developed as RaaS (robot-as-a-service) to help small-and-medium-Sized Manufacturing Companies (SMM) to deploy and operate cobot automation without in-house robot experts. This cobot service program helps lower ROI as well as enhance the productivity of SMM by providing a total care service from cobot planning to installation. The following is a case introduced by a company as a cobot service program.

The Cobot Service Program (CSP) developed originally by Neuromeka [11] is a kind of a cobot care program for deployment, operation as well as maintenance of cobots for clients at a reasonable cost. The goal of the CSP is to save efforts made for cobot system integration from choosing cobots to maintenance and in turn lower the barrier to adopt cobots for SMM. In order to achieve this goal, the CSP provides a customized cobot service including cobot automation layouts and human-robot collaboration plans throughout the process analysis of SMM. In particular, the CSP includes a financial plan with a leasing and monthly subscription model to minimize the initial investment cost and a personnel training program related to building in-house robot experts.

The core of the CSP is to send an on-site cobot specialist in order to introduce, maintain, and train cobot automation. He/she is dispatched to the production line of SMM to communicate directly with field managers monitoring workers' tasks to provide a cobot automation plan that can effectively change a manual production process. Besides, he/she provides a personnel training program about how to use a cobot and solve cobot-related problems to become a competent and skilled cobot specialist. With an on-site cobot specialist under CSP, customers can conduct their own cobot automation using in-house trainees at a lower cost (Figure 5).

Figure 5: Deployment schedule of IndyGO.

CONCLUSION

Cobots are a more recent development where robots work alongside humans rather than replacing them. It can be installed without safety fences guaranteeing faster ROI (return-on-investment), from the standpoint of managers, by resolving the skill gap issue as well as relocating experience workers to more value-added production lines. Collaborative robots have been developed to free human workers to perform repetitive and/or monotonous tasks whilst they can focus on work that requires lean thinking that increases the efficiency of the production process they are working on. In addition, the high flexibility and easy reprogramming of cobots allow us to penetrate the market of industrial robots and grow at comparable growth rates.

It's likely that cobots will move forward toward complementing human workers and freeing them up for higher-level tasks; however, they will still replace certain low skill workers. As such, understanding the strengths and limitations of cobots is especially crucial to chart a successful implementation. Choosing the wrong type can restrict your future growth; choosing the right course can unlock more efficient production and reduce costs for years to come.

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