

A Framework for Collaborative Robot (CoBot) Integration in Advanced Manufacturing Systems

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ABSTRACT

Contemporary manufacturing systems are still evolving. The system elements, layouts, and integration methods are changing continuously, and 'collaborative robots' (CoBots) are now being considered as practical industrial solutions. CoBots, unlike traditional CoBots, are safe and flexible enough to work with humans. Although CoBots have the potential to become standard in production systems, there is no strong foundation for systems design and development. The focus of this research is to provide a foundation and four tier framework to facilitate the design, development and integration of CoBots. The framework consists of the system level, work-cell level, machine level, and worker level. Sixty-five percent of traditional robots are installed in the automobile industry and it takes 200 hours to program (and reprogram) them. Integrating CoBots has the potential to enhance the abilities of both the robotic and human actors within the system, improving process efficiencies, and adapting to changes. A thorough review of the literature, safety and layout challenges, and contemporary factory automation configurations using solutions that have been introduced to the market will be presented, as well as a roadmap for education and research challenges.

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INTRODUCTION TO CONTEMPORARY ROBOTIC SYSTEMS

Robotic systems are utilized in many applications today, such as paint and sealant applications, welding, assembly, material handling, inspection, and so forth. These tasks are highly repetitive and may be performed in environments and conditions not appropriate for humans. A comprehensive set of robot structures have since been designed and built to fulfill the industry needs in many domains (automotive, aerospace, etc.). These multi-Degrees of Freedom (DOF) structures are highly complex in their form and control. Most manipulators used in the industry today are articulated with six or more rotational joints. This structural form provides the manipulators with a great deal of flexibility, dexterity, and an ability to reach every specific coordinate of their workspace in more than one configuration. Sophisticated simulation tools are used for path planning, and complex control strategies are employed to control the positioning, velocity, acceleration, jerk, joint wrap, etc. This basic foundation for automation is being expanded upon. Current robots, such as industrial robots, medical robots, robots in space, etc., are designed to do tasks that a human is not able to do. New human / machine interface interactions strategies are being developed: collaborative robotic

systems or 'CoBot' systems. Why are CoBot solutions being introduced? This integration strategy leverages the 'strength' and 'endurance' of robots with the flexibility and decision making of human participants. Unique kinematic structures and process planning strategies are presently being launched. Therefore, the goal of this research is to review the literature, highlighting the challenges, and use this information to provide a foundation and four tier framework to facilitate the design, development and integration of 'CoBots'. It must be emphasized that CoBots are designed to be a complementary working tool for human workers, and that this perspective guides design and implementation criteria.

Current State Relating to CoBots

A 'CoBot' (from collaborative and robot) is a robot intended to physically interact with humans in a shared workspace [1]. Initially invented in 1999 by Professors Edward Colgate and Michael Peshkin at Northwestern University in Evanston, Illinois [1], CoBots' are now a \$100 million segment of the industrial robotics market with continued growth projected at more than 50 percent per year [2]. As further evidence of the importance of this growing market segment to the US economy, ABI Research recently published a new forecast

putting the market for CoBots at over \$1 billion by 2020 [3]. CoBots have piqued the interest of many corporations from automotive and aerospace OEMs to small and mid-sized businesses [4]. Within the advanced manufacturing environment, Samuel Bouchard, President of Robotiq, indicates that many large manufacturers are considering CoBots and are starting to look at automation in different ways [5]. The current automotive industry relies heavily on robotics, according to Jim Lawton, chief product and marketing officer at Rethink Robotics. The good news, from his perspective, is that ninety percent of manufacturing tasks can be automated and he expects 150,000 CoBots to be installed worldwide in 3 years [5].

A recent Forbes article demonstrates how a CoBot at GM's Orion, Michigan assembly plant is assisting workers to pull spare tires off a conveyor and stack them based on their assigned vehicle. The article indicates the most challenging step was teaching the maneuver in a crowded workspace where people are usually two feet away. Humans need to learn to work with the CoBot before being able to consider it part of the team [6]. CoBots are becoming a staple on the production floor and are changing how we work [7,8,9,10,11]. This example is just one of hundreds of scenarios whereby humans will be required to learn to interact with their robotic partners. A predicted 150,000 CoBots are to be installed worldwide in the next three years, and it is expected that this new manufacturing paradigm will affect both productivity and workers' safety solutions [12, 13].

As shown in Table 1 and Figure 1, the standard characteristics of CoBots are summarized as follows:

Table 1. Comparison between Traditional Industrial Robots and CoBots

Traditional Industrial Robots	CoBots
Fixed installation	Flexibly relocated
Periodic, repeatable tasks; infrequently changes	Frequent task changes; Tasks infrequently repeated
On-line and off-line programming	Online instructed and supported by offline methods
Not easy to teach	Easy to teach
Rarely interaction with the worker, only if being programmed	Frequent interaction with the worker, even force/precision assistance
Worker and robot separated through fence	Workspace sharing with worker
Cannot interact with people safely	Interact with people safely
Profitable only with medium to large lot size	Profitable even at small lot size
Small or big and fast	Small and slow
Cannot reduce cost and footprint to justify new applications	Reduce cost and footprint to justify new applications
Not requested risk assessment	Requested risk assessment
Usually 6 axis with last three intersecting in wrist	Usually 6 and 7 axis with many offsets

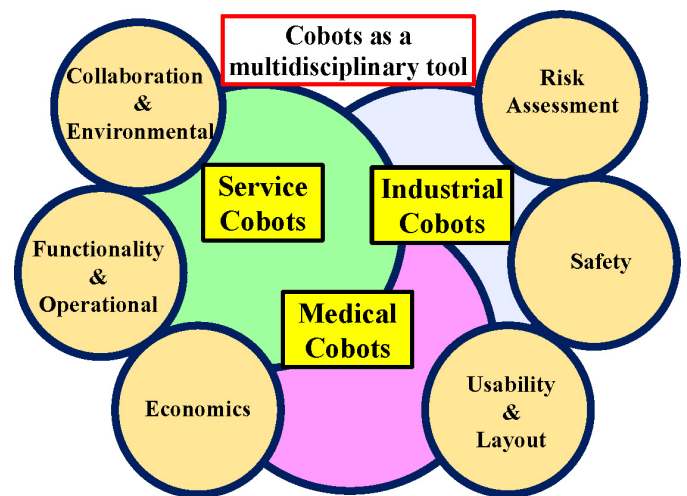


Figure 1. CoBots as a multidisciplinary tool for manufacturing, service, and medical applications.

EXISTING COBOT SOLUTIONS

At present, there are several CoBot solutions that exist. A review of commercially available CoBots is presented in Table 2 [14, 15]. It can be seen that there is a variety of manufacturers, and many CoBot structures do not adhere to the 'standard' serial 6 axis configuration. Several CoBots contain dual arm configurations. This should introduce offline and online programming complexity, but 'ease of use' is a key feature with CoBots. Specialized control algorithms, man-machine interfaces, and embedded sensors to address collision and safety concerns solutions are embedded within the present solutions to allow for rapid reprogramming and task management flexibility.

Table 2. Summary of current CoBot solutions [14, 15]

Commercial Name	DOF	Charac
ABB FRIDA - YuMi	Dual-arm 7+7	Flexible, accessible not spending more time on process than to program
ABB – ROBERTA	6	Light weight, 6 DO singularity points, g structural weight ra
Bionic Robotics- BioRob Arm	4-5	Lightweight robot, i and place, inspectio applications
BOSCH – APAS	6	Unique safety featu this CoBot solution perimeter that slow: once a person gets t
FANUC – CR-35iA	6	It has accuracy and industrial robot, but easy to employ all I sensors
F&P Personal Robotics -Prob 1U	6	Easy to program an user interface), All-solution (arm, gripp advanced Artificial (customizable and r cover, color and axi
F&P Personal Robotics -Prob 1R		

Table 2. (cont.) Summary of current CoBot solutions [14, 15]

KAWADA INDUSTRIES - NEXTAGE	Dual-arm 6+6	It has a 'head' with torso, two 6-axis arms, the 'head' has freedom allowing it of vision with the v
KUKA - IIWA	7	It is design like a h seven axes. It has in each joint that allow position and sensiti delicate jobs due to performance collision algorithms.
MABI - SPEEDY-10	6	Lightweight design, 18-bit absolute enc positioning, intuitiv interface
MRK SYSTEME - KR 5 SI	5	Safe operation, mor and speeds of each order to respect the systems also have c sensors that detect e with the change of t
Yaskawa Motoman SDA10F dual-arm	15 axes 7+7 plus a single axis for base rotation	Superior dexterity, Both robot arms can one task.
PRECISE AUTOMATION - PAVP6	6	Lightweight, embed external controller), based interface)
Precise Automation - PF400-SCARA	4	Low-cost, quiet, lig combined with a vi
Precise Automation - PP 100-CARTASIAN	3	It has X, Y and Z a robot), and has unic because all the axes all situations.
Rethink Robotics - Sawyer	7	7 DOF and 1-meter sensing; High-resol embedded at each j Camera in the head view and Cognex c light source in the v vision applications.
Rethink Robotics - Baxter	Dual-arm 7+7	No Programming: F trained in minutes v system integration r designed and progr wide range of manu production tasks; vi aware of its environ automatically adjus
Universal Robots: UR3 UR5 UR10	6	Low-noise and ener very precise (± 0.00 teach, the software interface that makes can be customized.
Kawada HIRO	Dual-arm 6+1+2+6 (two arms 12, head 2, waist 1)	With a highly funct NEXTAGE and a h software environme a platform for cuttin
CoWeldRob	6	Modular and intera concepts and contr efficient use of robo applications.

'COBOT' FRAMEWORK

As a CoBot based solution balances the advantages of advanced automation with the adaptability and decision making of human participants, unique design strategies must be considered from the systems level to the man-machine interface levels. A multi-perspective systems viewpoint is used to represent and map these requirements. The Zachman framework [16], used for enterprise architecture design, is modified in order to be used for CoBot applications (Figure 2).

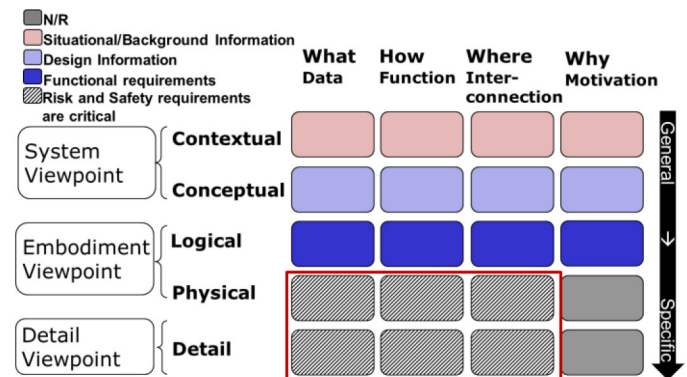


Figure 2. CoBot design and implementation framework illustrating the multiple key perspectives to be considered

The framework matrix consists of a vertical axis that provides multiple perspectives of the overall architecture and a horizontal axis, which provides a classification of the various elements within the architecture. Although enterprise architecture frameworks are very powerful for examining aspects of a business and its interactions, the Zachman Framework provides a solid, non-specific structure that can be readily transformed to provide a foundation to represent the CoBot design and implementation challenges, as many perspectives must be considered to effectively design, operate, and maintain as system. A selection of key attributes to be evaluated at the various viewpoints is shown in Figure 3.

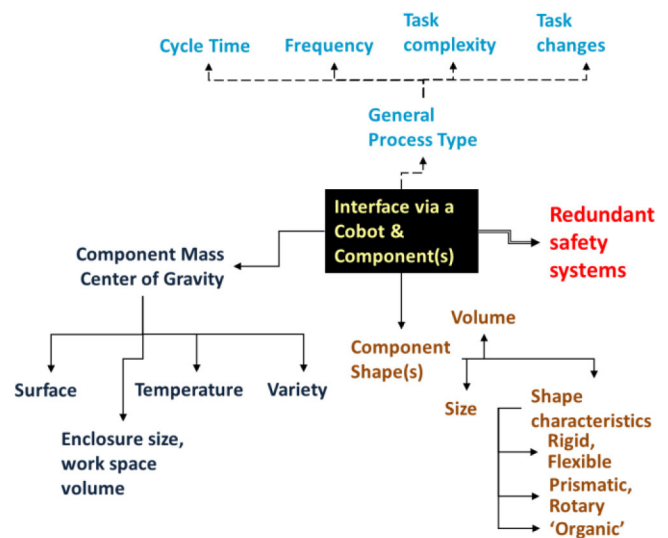


Figure 3. Essential component-process-CoBot interactions