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An open-architecture integration solution for the research and development of smart robots

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Abstract:

Many key factors driving the Fourth Industrial Revolution (Industry 4.0) are to construct industrial robots to become increasingly intelligent, multi-functional, flexible, and efficient, as well as a complementing platform for collaboration with people. The latest generation of intelligent robots, known as Cobots (collaborative robots), can now cooperate and stand side-by-side with humans in a safe way and perform many tasks that require the same skills as humans. This paper firstly overviews the new generation of Cobots used for manufacturing and other applications to see forward into the future. Secondly, we briefly mention innovation technologies that should be integrated and extended deeper into smart robots to develop their applications in smart manufacturing, science and technology, high education, and so on. As a result, it is necessary to build new prototype robot systems that possess open hardware and software architectures for the development of both their smartness and dynamic skills. The main content of this paper will propose an open-architecture system for smart robots as well as like-robot machines using a CompactDAQ platform from National Instruments (NI). In the end, some information about the realized system implemented at the Institute of Mechanics of Vietnam Academy of Science and Technology will be shown for far joint discussion.

Keywords: **cobots, DAQ systems, integrated systems, motion control, smart manufacturing, smart robots.**

Classification number: **2.3**

Introduction

Industry 4.0 is an inevitable trend that is changing the way people live and work. This revolution brings opportunities and challenges to development in every country around the world. The manufacturing industry is a major part of the economy where people are increasingly resorting to mechanization and automation. Industry 4.0 is shaping smart factories based on smart manufacturing systems with highly flexible automation (autonomous systems) where machines, operators, and other resources can communicate together to create products in smarter and more organic ways. In a smart factory, a software-controlled system monitors physical processing and replicates the physical environment by creating a virtual replication. Based on the self-organization mechanism, the software-controlled system will make decentralized decisions for production processes. Next, Industry 4.0 will not only focus on individual factories, but also include the integration of many production facilities, service systems, and supply chains to achieve value-added networks.

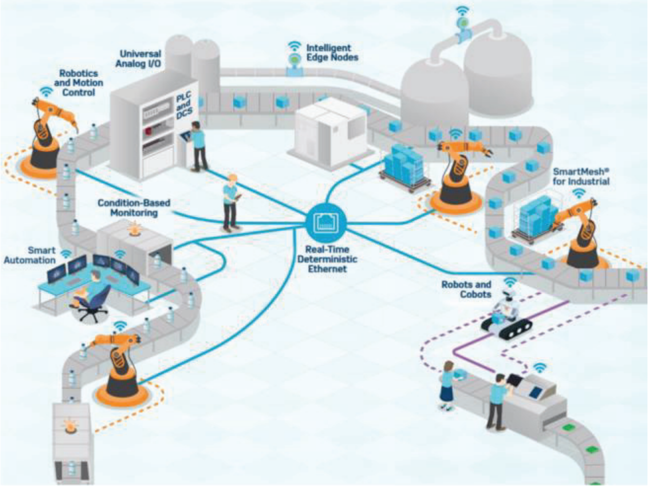

Fig. 1. The secure connected enterprise.

Industry 4.0 refers to a comprehensive cyberspace physical integration of corporate operations using the internet (industry) and everything integrated with operational technology (OT) and business systems (IT). This revolution will allow ecosystems that

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link vendors, partners, distributors, and users in a robust value chain driven by simultaneous advances in cloud computing, communication infrastructure, and advanced technologies that help narrow the digital world (Fig. 1). However, technology at the edge of the network (where data is generated) is becoming increasingly important to ensure the integrity and value of information across the system. They need to be designed at a systemic scale with many technological challenges. This technology itself is not enough, but it is necessary to realize the vision of Industry 4.0 with innovative approaches, technical models, and deep expertise. The old convention "who does what" in the industrial ecosystem will be challenged and new partnerships will emerge. In general, the basic structure of a smart factory model includes intelligent machines and flexible automation systems; robots and smart actuators; application of artificial intelligence (AI) technology; all connected devices - Internet of things (IoT); and big data.

To this day, the automation strategy model of A. Granlund, N. Friedler (2012) [1] is used for the process of integrating traditional industrial robots in the production system to increase production efficiency and replace operators who perform heavy, repetitive, and insecure work [2]. Traditional robots require an isolated robot cell to avoid direct human contact and are limited to a fixed position with a preprogramed task [3]. Compared with traditional robots, the new generation of intelligent robots, or Cobots, can collaborate with people to complete co-tasks [4], thus demonstrating interactions between people and robots. The technology also introduces a new concept of workplace design where a human-robot collaborative work cell can be described as a co-working and coordinated workspace encompassing Cobots performing tasks to suit the operator. Communication between Cobots and humans must be accomplished to fulfil certain requirements (friendliness) [3].

Recent years have witnessed an explosive expansion of the global robotics market, bringing in significant progress and maturity in robot technology. The leaders in robotics technology around the world include MIT Institute of Computer Science and Artificial Intelligence; Stanford AI Laboratory; the Robotics Institute of Carnegie Mellon University (CMU); Georgia Institute of Technology's Human-Computer Interaction Research Facility; Waseda University's Human-Robot Research Institute; The University of Tsukuba Smart Robotics; The Robotics Center and Mechatronics Center (DLR), and the German Aerospace Institute, etc. These institutes have been contributing to the research and development of intelligent robots, creating a treasure trove of human intelligence about robots. At the same time, there are many well-known robot companies including ABB (Switzerland), KUKA (Germany), Yaskawa Electrics and FANUC (Japan), Northrop Grumman, iRobot, Visual Surgical Robot (USA), ABP (UK), Saab Seaeye Underwater Robot, Reis Robot Group (Germany), Pesco (Canada) and Aldebaran (France), which have formed many pilot industries in their respective countries or regions, and have made remarkable contributions to the application and marketization of robots. In addition, several large businesses have held robotics competitions to accumulate solutions to industry-specific or robot-related problems with well-known titles include the Amazon Item Pick Challenge with Edge Logistics [5], the Unmanned Driving Urban Challenge [6], the DARPA Robot Challenge [7], the NASA Return Robot Challenge [8], etc. These robot events have wide attention around the world and encourage effectively promoted robot technology, but also provided a good opportunity to conceptualize and build a large playing field that helps enhance communication between robot development teams and applications. Many research institutes and robotics companies have made emerging breakthroughs in many related fields such as dual-arm collaborative robots, AGV intelligent logistics technology, unmanned driving technology, medical operation and rehabilitation robots, intelligent service robots, and dedicated robots.

Cobots, with the ability to work collaboratively with people, are typical representatives of the next generation of intelligent industrial robotics. Fig. 2 shows some famous collaborative robots. The intelligent collaborative delivery robot of the Rethink Company (USA) can either complete work independently on the work floor or cooperate with workers to control, pack, and process materials. This Cobot uses infrared sensors to detect approaching objects and cleverly avoid collisions [9]. In 2015, the ABB Company developed a dual-arm structured Yumi robot integrated with vision technology, instructional programming, precision servo control, and collision avoidance mechanism. These technologies help the robot complete smart assembly operations based on visual guides and force control and responds to demand from the consumer electronics industry for both flexible and traditional manufacturing [10].

Fig. 2. Famous human-robot collaborative robots.

Likewise, there are many other robots, including the UR series from Universal Robots; CR-35iA from FANUC (with a maximum payload of 35 kg); and the LBRiiwa and Automatic Pickup (AIP) technology from KUKA and Swisslog. In the field of medical surgery, intelligent robots can guarantee lower blood loss, higher resilience, more accuracy and agility; and possess great commercial potential. In 1985, the Puma 560, which was the first robot used in surgery, participated in a brain biopsy by providing brain locator services. In 1997, AESOP performed the first laparoscopic surgery. The first version of the da Vinci surgical robot was born in 1999 (Fig. 3). Currently, there are nearly 4000 fourth generation da Vinci robots in the world. This robotic product has performed over 4 million surgeries and is known to be the most successful medical surgical robot in the world to date [11].

Fig. 3. The da Vinci surgical robot.

The Miro robot developed by the DLR Company (Germany) for cosmetic and orthopaedic surgery has a weight of only 10 kg [12]. The ViRob, a microrobot for automatic information collection from the medical company Microbot (Israel), appearing in 2015, can be controlled remotely via electromagnetic waves. This robot can provide cameras, drugs, or devices to narrow and twisted areas of the human body such as the blood vessels and the spinal canal, thus assisting doctors in minimally invasive surgeries. In 2003, a robot was designed to aid brain surgery, and its fifth generation has been introduced into clinical practice [13]. In 2013, the "Minimal Invasive Laparoscopic Surgical Robot System" was successfully built by the Robot Institute of Harbin Institute of Technology. This robot achieved emerging breakthroughs in technologies including master-slave control algorithm, machine design, and 3D peritonitis [14]. There are many other medical robots around the world, for example, the SpineAssist of Mazor Robotics (Israel) is used to regenerate and heal the spine. Carnegie Mellon University's master-slave CardioArm S-shaped robot consists of more than 100 joints and can be applied for minimally invasive heart disease surgeries. Rosa Brain and Rosa Spine robots of Medtech (France) are used as surgical support platforms. Most of these robots take the form of a single-arm structure or a combination of two arms or dual-arm robots.

Despite moment capabilities and advantages in certain circumstances, single-arm robotic systems have limited manipulations of dexterity, approach, and lifting capabilities. Continued advances in dual-arm robot technology offer a significant advantage over single-arm applications. With the dual-arm robot system, skilful and precise manoeuvring is sure, as the robot acts as an extension of the operator. A dual-arm robotic manipulation system provides the skill to stabilize an object with one arm while allowing the other arm to manipulate the object. This advance will help robots perform tasks that are particularly difficult and time-consuming for single-arm robot systems, such as removing bottle caps, unpacking, ruck sacking, and pulling items apart. In contrast, a dual-arm robot system can mimic operator movements to perform dangerous, complex tasks with human-like skills that neutralizes threats from a safe distance.

In the long term, an intelligent robot is a very modern, interdisciplinary, and multi-field integrated system capable of connecting IoT based on big data, cloud computing, and high-speed communication networks making them suitable for the current digital transformation trend. The process ranging from mastering the art of design, integration, manufacturing, and development of robot applications to construction in the robotics industry is essential to creating a smart manufacturing ecosystem and other values (Fig. 4).

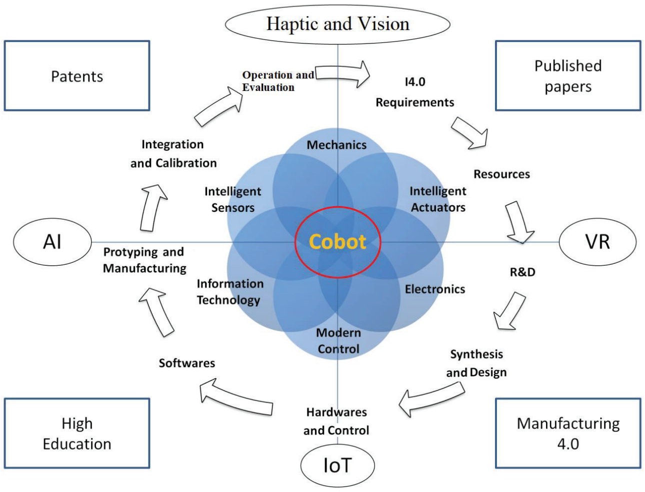
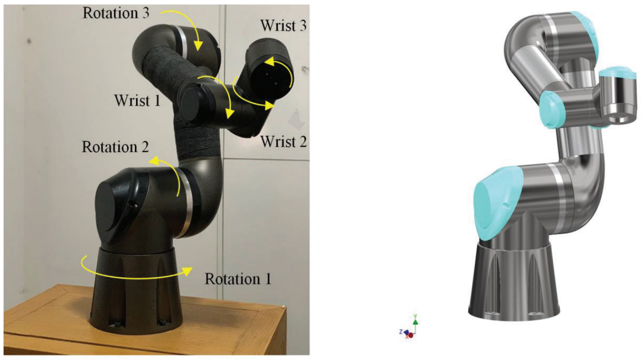


Fig. 4. The state-of-the-art of Cobot integration.

Innovative technology related to robotics

Compared to the most important and leading technologies involved, at present, intelligent/smart robots have non-complicated intelligence and relatively basic functions. They behave hardly in circumstances requiring human-robot cooperation under complex situations and have difficulty responding to user needs. It is needs to go over these technical drawbacks for the next steps. First, human-robot collaboration, and R&D on key technologies such as multi-modal awareness, environmental modeling, and decision-making optimization will be pushed to enhance the collaborative relationship between humans and robots. Second, robotic technology will be deeply integrated with the IoTs, big data, and cloud computing. Similarly, large sharing of data and computing resources will be fully utilized, which in turn will enhance the ability of intelligent robots to serve. Furthermore, AI technology such as emotional interaction, image recognition, deep learning, and brain-like intelligence must be deep developed and used to build robots capable of intelligent decision-making at a high level, ensuring safety and reliability. In addition to the above technological drawback, there are several new challenges emerging in the way to innovate robot technology: How to effectively utilize the industrial chain to conduct R&D cooperation; How to improve operation system for robots; and how to find innovative solutions to integrate multiple fields smoothly need to be answered. Research and innovation on leading technologies are critical to the formation and development of a nation's future emerging industries along with data and cloud-based network decision-making mechanisms and big data.



(A) (B)

Fig. 5. The SM6 Cobot: (A) real robot and (B) 3D CAD model.

Figure 5 shows two pictures of the SM6 Cobot developed by the Mechatronics Department, Institute of Mechanics, Vietnam Academy of Science and Technology. In the figure, from left to right, is the image of a real robot, then the 3D simulation model, respectively. This robot reaches some features in Table 1 below.

Table 1. Specifications of the SM6 collaborative robot system.

Type			**Articulated type**
Degree of freedom (DOF = number of axes)			06
Max. payload (kg)			approximate to 2.5
Positional repeatability (mm)			approximate to ±0.1
Motion range (°)	Arm rotation 1 (°)		-360 to +360
	Arm rotation 2 (°)		-360 to +360
	Arm rotation 3 (°)		-150 to +150
	Wrist 1 (°)		-360 to +360
	Wrist 2 (°)		-360 to +360
	Wrist 3 (°)		-720 to +720
Controller	Number of controlled axes		6 to 8
	Drive system		full digital servo system
	Type of motion control	Manual mode	coordinated movement, individual movement, motion tracking, [Interpolation mode] joint, base, tool
		Auto mode	coordinated movement, individual movement, motion tracking, [Interpolation mode] joint, linear interpolated motion
	Force Control		yes
	Programming		direct teaching method through tablet
			hand by hand
			haptic device
			vision
	Safety mode		stop or speed reduction to specific situations
Connection			ethernet
	Gripper		two figures and other tools
Mass (kg)			approximately 20

In the next phase, this robot system will be continuously developed by extended and deep integration processes with innovative technologies aimed to be more intelligent.

Technology for designing and manufacturing robots

Robot technology is a complex and advanced technology involving multiple disciplines and interdisciplinary industries including mechanics - electronics, automatic control, sensor technology, computer - information technology, new materials, biotechnology, and artificial intelligence (increasingly to become more integrated and expanded). Robot manufacturing technology is “an advanced technology” of the human race, closely related to a multi-stage process from theoretical research and technology development to technical applications using interdisciplinary integrated thinking. The mechanism between "software" and "hardware" of the system includes many physical components, technologies, and knowledge from many diverse fields. Fig. 4 shows the backbone process for creating general robots like the SM6 robot. Now, it is time to refresh this process for intelligent robots for a new robot generation integrated with novel technologies.

The technology of cooperation between humans and robots

Human-robot collaboration plays an unlack role in the next generation of intelligent robotics. ISO issued the latest robot production standards in 2016 [15]. To realize a coexistence of robots and men, human collaboration robots need to be safe, comfortable, adaptable, and easy to program. Safety means protecting people from dangerous injuries that could result from robots during an interaction. Comfortability means that a robot's actions are subject to human cognitive habits and thus humans can predict a robot's intentions. Adaptation is when robots can be able to understand human needs and precisely adapt to human movement and various tasks. Easy programming means that people can easily program, learn methods of operation, and control robots. Therefore, cooperative robots with the four following activities are required:

Safe stop: This operation forces the robot to stop before humans enter the robot's workspace. The aim here is to keep people secure and prevent exposure to risks or dangers in the workspace.

Manual human guide: This will give humans access to control the robot by leading the robot’s moves and operations.

Speed monitoring and separation: This aims to reduce speed when people enter the work area (a safety scanner can be used [16]). The distance between the robot and person is always measured such that the robot either stops, slows down, or backs away from a person to maintain safety [17]. The speed of the robot will decrease if a person moves close to a robot, and, if they move too close, the robot will automatically stop for safety reasons.

Force limitation and force control: A focus on avoiding injury and pain that robots can cause to humans. To avoid injury and pain, it is necessary to limit the robot's speed as well as force. Therefore, the ability to injure humans will decrease [16].

The main technologies to be achieved include the design of a hard-soft-flexible coupling mechanisms [18-20], intelligent drive technology, safe decision-making mechanisms geared towards human-robot cooperation [21, 22], 3D modelling of environments [23], interactive force sensing and control, a distributed collaboration of multi-agent systems, vision-based image processing [24-26], furthermore emotional recognition and interaction mechanisms toward the friendly cooperation between humans and robots.

Technology for multi-robot systems

A multi-robot system refers to an identified number of independent robots that take moving and cooperate as a self-organizing group. Such collaborative action can help the team realize complex functions and demonstrate a clear trend towards the "in projects" or "goals" collective [27]. Studies of multi-robot systems will focus on the aspects such as increasing the convergence speed of coordinated control and dealing with finite-time control [28], transforming the topology of system changes over time, and organizing the multi-agent network in a more proper way [29], designing a program that estimates according to the global non-linear collaboration state, and realizing differential co-operative control groups of robots based on a heuristic algorithm [30].

Compared with the traditional single-robot system, there is no global control goal however there is distributed control issue in a multi-robot system. Multi-robot collaboration improves efficiency in the execution of tasks and its lifetime enhances the robustness of the system can complete distributed tasks that a single-robot system cannot do. Furthermore, the multi-robot system is easily expanded and updated. Each robot has relatively basic functions and a limited ability to collect, process, and communicate information. Through transmission and interaction between robots, the whole system will be highly effective in collaboration and higher intelligence performance, thus achieving many difficult and complex jobs. Impurity requires high precision and is beyond the capabilities of a single-robot system [31]. Multi-robot systems demonstrate great power in multi-sensor collaborative information processing, multi-robot collaboration, drone fleets, multi-operation control, and other fields [32-34].

The technology of control and decision-making is like the brain

With robots' deeper and broader involvement in industrial production and the social life next generation, thus it will be required to increase their performance. Robots usually serve in complex and interchangeable environments with unpredicted uncertainties, and missions are of a high hermaphroditic and nonlinear nature, performance requirements go beyond the validity and plausibility of common control algorithms. Capable of rich sensor data collection capabilities, the robot can perform sorting, synthesizing, and extracting data efficiently and reliably in the future (Fig. 6).

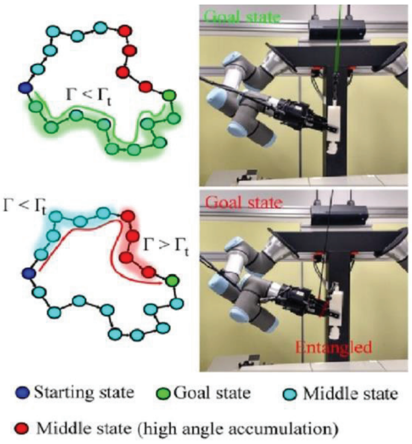


Fig. 6. Training a robot in object grasping based on deep learning.

Robots possess strong learning abilities including supervised or unsupervised learning. Supervised learning will train logical model parameters based on artificially labeled sample sets from which manipulation control decisions are made. In contrast, unsupervised learning will train optimal control laws from the unlabelled sample sets [35]. Supervised learning meanly focuses on imitation and performance [36, 37]. A. Paraschos, et al. (2013) [38] proposed the primitive probability of motion (ProMP), which describes primitive motion using probabilistic modelling that allows the robot to adapt to changing tasks. In several studies [39, 40], the sub-primitive motion constructs a compact expression of robot control laws used to perform actions such as collision, impact, and capture. Robots can mimic human actions and adapt to different circumstances by adjusting their primitive parameters of motion. Unsupervised learning is mainly focused on building complex neural networks and deep learning. Deep learning was proposed by Hinton, which simulates brain function learning by applying neural networks. S. Levine, et al. (2016) [41], C. Finn, et al. (2017) [42] deployed unsupervised learning by establishing a larger neural network. The robot can plan strategies while being trained as well as build a mapping relationship between robot movement, sensory information, and mission, thus helping the robot complete the task without human intervention such as closing and opening doors and holding items (Fig. 6). Based on the multi-layered expression mechanism in the brain, such an unattended feature learns and recognizes deeply abstract expressions from the original game and avoids artificial interference in this process to export geometric objects.

Moreover, deep learning theory, to some extent, helps solves the problem of local convergence and is more adaptive in previous artificial neural networks.

Virtual reality technology for robotics

The new generation of intelligent robots will feature high connectivity, virtual-real linkage, intelligent software, and human-robot collaboration. More specifically, the robot can collect a lot of rich data from diverse sensors and upload them to the cloud to process and share information. Virtual and real devices are deeply integrated forming a closed process of collecting, processing, analysing, responding to data, as well as executing and implementing "real-virtual-real" transformations. The smart algorithm to analyze big data based on advanced software applications enables the new generation of intelligent robots to thrive in a softwareization, content-depended, centralized platform API. Robots can be able to realize human-robot interaction using images and videos, even sense man's psychological activities, and exchange emotions applicating deep learning. The smart robot number is gradually expanding and becoming more systematic, essentially building an all-round chain and welcoming impressed technological innovation.

The technology of a robot's network based on cloud computing and big data

During the 2010 International Conference on Humanoids, for the first time, J.J. Kuffner, S.M. LaValle (2011) [43] presented the concept of a "cloud robot". Cloud robots are an integration of cloud computing and robotics. Cloud computing is an internet-based computer mode. Software, resources, and information can be shared and made available to endpoints according to business needs. Like a terminal network, the robot does not need to store all the data or possess powerful computation but must link up with relevant servers to obtain the information it needs. Cloud robots can not only upload complex computational issues to the cloud but can also get a lot of data and exchange both information and skills. It is more powerful than storage, computation, and learning, and makes it more convenient to re-share resources between robots. Additionally, the robot will bear a smaller burden under similar circumstances, thus saving developers time by eliminating repetitive work [44]. Many companies like Google, Microsoft, and Baidu are involved in a computing cloud and big data technology research. Various cloud robot service architectures have been presented including a cloud service platform for networked robots (ex: ROS platform [45] and RoboEarth platform), a cloud service platform for sensor network (e.g., Sensor Cloud [46] and X-sensor), and a cloud service platform for the RSNP Model (e.g., Jeeves platform) [47]. The development of big data and cloud computing will drive development in the realm of robotics such as object capture, SLAM, and emotional perception. Notably, AS ORO Laboratory from Singapore has built a cloud-computing system that allows robots to build 3D maps of the environment at a much faster rate than the computer connected to the robot [48]. B. Kehoe, et al. (2013) [49] from the University of California, Berkeley, completed the task of capturing via a cloud-based 3D robot using a PR2 robot from Willow Garage Company and a target recognition tool from Google. Microsoft has developed an articulate Cortana personal assistant for conferences, which is dependent on cloud technology and can create a comfortable conversation with everyone. It can examine if it is the same talker or not during the conversation. Google's DeepMind developed and improved the AI architecture AlphaGo, which overcome many Weiqi experts around the world [50]. Cloud robot technology, as well as its unique advantages integrated with big data and cloud computing technology, are going to spark a huge transformation in the field of smart robots.

With ever-deepening industrial reform, changing social needs, and technological advancement, robots in the world are undergoing never seen growth. Countries around the world are competing in pushing robot innovation strategies. Third backbone technologies represented by big data, cloud computing, mobility, and social interaction drive the global robot industry growth towards intelligence, innovation, and digitalization. In the future, along with the development of smart hardware and AI technology, intelligent robots will surely make great progress and be broadly used as collaborative robots in unmanned vehicles, medical care, logistics, education, and entertainment. The diversity of user needs and the increasing emergence of never seen technologies push robots to evolve in highly intelligent, highly adaptable, and network-based ways.

A proposed open-architecture employed NI technologies for robotic development (the SM6 Cobot)

In essence, the general architecture of a robotic system needs to meet the requirements of implementation from basic to advanced skills and learning abilities. In traditional manufacturing, the main skill of robots is to perform motion tasks considering interactions of forces with the environment, while intelligent robots will develop the self-learning ability to collaborate directly with humans. To adapt to this requirement, there have been various solutions developed based on so many different software and hardware platforms throughout two phases including expanded-dimension integration (open sources) and deep-dimension integration (packed sources).

In this paper, we propose a hardware and software architecture employing the NI CompactDAQ platform aimed to integrate and expand innovative technologies into robotics for the development of smarter robots. The latest CompactDAQ system can perform both control and acquisition functions at the same time, providing data measurement that meets inspection requirements without limitations in terms of distance and environmental conditions. This device typically pairs with I/O modules that provide communication to the sensor using software optimized for both industrial and R&D applications. There will be solutions made of data acquisition modules that can synchronize multiple measurements over a network bringing the data digitization system closer to the sensor thereby reducing noise and simplifying wiring connections.

A CompactDAQ system can be easily connected to your PC via USB or Ethernet and then integrate one or more I/O modules for direct communication with sensors. Users can choose from a built-in controller that works with Windows or a real-time operating system like Linux to run independently. The CompactDAQ controller is a tightly integrated, reliable, high-performance industry standard. It is an ideal solution for collecting and analysing data in built-in or portable memory. Obviously, this unit also allows for many standard connectivity and expansion options including USB, Ethernet, CAN/LIN, and RS232. In addition, the integrated solution can be expanded with high-quality input and output modules (C Series) to provide signal conditioning and analogue-to-digital conversion for CompactDAQ systems (NI currently offers up to 60 C Series I/O modules to interface with most sensors on the market, in a quick and easy way for a size-optimized, cost-optimized custom hardware setup with good performance). Note that these modules can be hot-swappable and plugged directly into the main machine, enabling customers to easily build a system to suit specific test requirements. The aforementioned allows processes from data collection and analysis to measurement system programming to be fully automated and seamless, so that tests can be flexibly tailored to specific needs.

CompactDAQ hardware is built to work well with DAQExpress™ software, FlexLogger™, and visual language programming environments such as LabVIEW to meet extensive development requirements and even deep integration. Not only that, but the CompactDAQs also use the powerful NI-DAQmx driver, making it possible to write programs in many other languages.

For motion control purposes, NI strongly supports testing, measurement, and control platform of mechanisms, machines, robots, and so on. In this application, the system will further integrate C Series and interface modules for CompactRIO and EthernetRIO, or PCI and PXI plug-in motion controllers. Combining this hardware system with the use of LabVIEW software, a multi-purpose controller, and a complete range of motors and drives, customers can build a variety of advanced multi-utility motion applications quickly and with lower costs.

In practice, motion systems are often built upon application software, motion control, actuators, and other mechanical components. The lower part of the motion control architecture is implemented at a hardware level close to what is required by the application, for example, initial setup, supervisory control, trajectory generation, trajectory interpolation, and control loops (position, velocity, torque).

NI currently offers two different motion architectures programmed with different software (Fig. 7). One architecture uses the NI plug-in motion controller in conjunction with motion-enabled NI-Motion controller programming, while the other uses a real-time controller and FPGA for programming with the LabVIEW SoftMotion Module (Fig. 8).

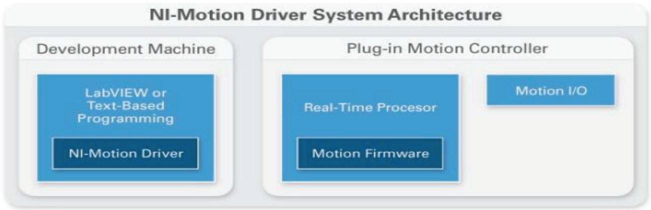


Fig. 7. Plug-in motion controller architecture.

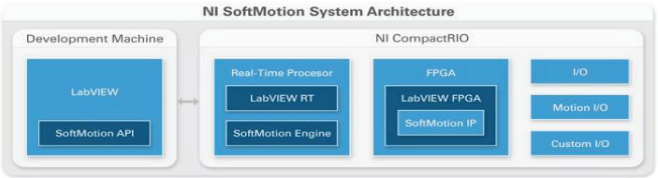


Fig. 8. Motion system architectures.

SoftMotion is a solution for software-based motion control, where various motion control components are modularized such as supervisory control, trajectory generation, and control loops (Fig. 8). Each component is then routed to a central motion system (developing machine, real-time processor, or FPGA) tailored to a specific application purpose. Customers can fully use SoftMotion for advanced application development from scratch, or customize it at the application code level, real-time SoftMotion Engine, or IP FPGA level. When using SoftMotion in conjunction with LabVIEW, it helps to quickly configure motion setup, simulate, link drivers to hardware, and test and adjust motion setup before application development. NI cRIO platforms are used to build an open architecture for integrating intelligent robots in several types of constructs: single-arm Cobots (Fig. 9) and dual-arm Cobots with a proposed systematic diagram as shown in Fig. 10.

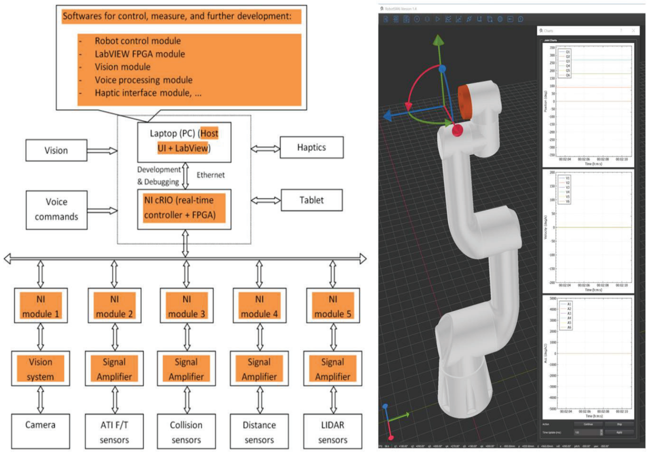


Fig. 9. A systematic diagram for open robotic architectures.

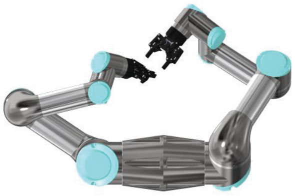


Fig. 10. 3D Simulation of the dual-arm SM6 Cobot.

Alternatively, the NI-Motion driver can be inherited to program the motion controllers on PCI and PXI (e.g., NI 7330, NI 7340, NI 7350, and NI 7390). This driver includes LabVIEW VIs (with examples) that will help users quickly create motion control applications using LabVIEW for Windows plug-in controllers or real-time LabVIEW. In addition, NI offers a wide range of easy-to-connect, reliable driver solutions to its embedded controllers that perform well in a variety of power ranges and are compatible with many other third-party devices.

Figure 11 shows a hardware and software system based on the solution of this paper that has been implemented for directly developing SM6 Cobot at the Automation and Mechatronics Laboratory of the Institute of Mechanics, Vietnam Academy of Science and Technology, as mentioned above. Also, this system is expected to help develop intelligent systems like robots.

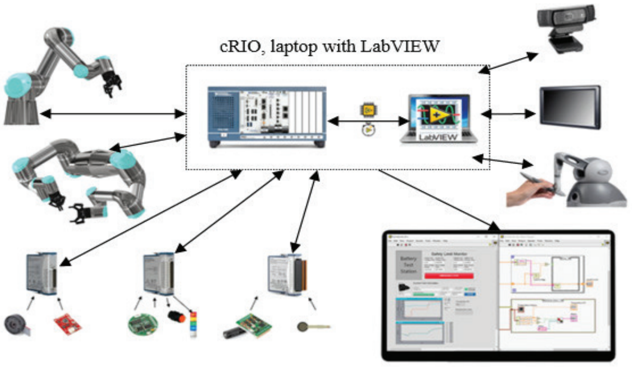


Fig. 11. A hardware and software system using NI devices for robot development.

Conclusions

Intelligent robots are predicted to liberate the manufacturing industry not only within the Fourth Industrial Revolution, which will root from automotive, electric-electronics, metal-mechanical, biomedical, and other industries. Developing a novel integrating solution will help capture this future opportunity for Vietnam by the intensive focus on automotive, electric-electronics, medical, other advanced technologies, and will step-by-step create a smart manufacturing ecosystem with the contribution of intelligent robots. First of all, it will develop in-depth knowledge, design, and prototypes of intelligent robots to help raise society's awareness of robots, artificial intelligence, Internet of things, virtual reality technologies, and other related fields in Vietnam. After that, based on the previous results, it will prepare the technology database to transfer, consult, support, and take joint development with enterprises aimed to commercialize products and services successfully. These goals will be achieved by concurrent streams of supporting activities like scientific publications and collaborative workshops, engagement with the manufacturing industry, especially in smart manufacturing, and continuous training generations of engineers at various levels.

The SM6 robot introduced in this paper is the second version and was just completed in 2021 (the first one was completed in 2018). The latest version is expected to integrate with more expanded and deep innovative technologies including many other techniques for both dynamics skill improvement and smartness. To realize this expectation, the authors propose a new hardware and software architecture using the cRIO platform from NI opened for integration development of new robots.

Interdisciplinary integrating solutions help develop in-depth research in related fields like robotics, mechatronics systems, control, AI (machine learning, deep learning), IoT, VR, cloud computing, big data, simulation, and embedded systems. Furthermore, it contributes to close links between domestic and foreign research groups. All these aspects help build and develop a deep and wide cooperative relationship between research institutes, universities, and enterprises in the innovation progressing trend.

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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