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Research Article

New Software Concepts for Controlling Industrial Robots

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Abstract-The use of industrial robots is associated with the use of proprietary manufacturer-specific programming languages. Interfaces to programmable logic controllers or other interconnected systems are always designed individually. This article examines some existing concepts of robot programming and identifies the need for their standardization and simplification. In order to assess the potential of uniform inter-manufacturer interface concepts, first approaches based on the PLC open Coordinated Motion specification are analyzed with reference to possible areas of application. Detailed comparisons between the functionalities of individual solutions are not made.

Keywords: Robotics, Robot Programming, Mxautomation, Coordinated Motion.

I. INTRODUCTİON

Almost every day, new reports appear in the media about the use of robots and the elimination of human labor. The social impacts can be controversially discussed and sometimes have a direct impact on the treatment of the issue discussed in detail below. The number of industrial robots installed worldwide is increasing by about 10% per year. There are many reasons for this. Increased wages or physical relief for workers, increased production requirements and increased product quality are just a few of the issues that have led to the massive introduction of industrial robots into companies. However, the ratio of robots used per worker in the manufacturing industry is not uniform. In 2016, 631 robots were used per 10,000 workers in South Korea, while in China this number was only 68. However, China's figure is subject to significantly higher dynamics, since the number of robots used per worker has doubled since 2013. This fact shows that there is a huge potential for the future use of industrial robots, especially since wages in the manufacturing industry in China have increased tremendously and have more than doubled in the last decade. The increasing spread of industrial robots, regardless of the underlying reasons, requires new ways of thinking about the integration and operation of robots in future systems [1].

A general requirement of the industry here is the need for simplification. Less qualified personnel must solve more complex problems in less time. Parameterization replaces programming. Various specialists are being replaced by generalists with basic knowledge in many subject areas to program and commission various systems. Developments in the industry show clear trends towards cross-system solutions.

The PLC open organization, the OPC Foundation and the International Federation of Robotics are a few groups that strive for cross-manufacturer and cross-system standardization of processes or products.

This article analyzes the shortcomings in the design, commissioning and operation of robots resulting from the use of given software paradigms. Existing solutions are also evaluated and their potential for use in specific application areas is discussed. Current requirements in the industry are taken into account. The focus here is particularly on manufacturing industries. Robotic applications in the healthcare or consumer sectors are not discussed in more detail [2].

II. EXISTING CONCEPTS OF ROBOT PROGRAMMING

At the moment, there are a wide variety of concepts for the software-based integration of robots into production systems.These concepts are influenced by many sides. The following section describes relevant points that have a direct influence on the use of robots and have a detrimental effect on the implementation of certain technical processes or on the involvement of certain groups of people. The entire life cycle is taken into account, from project planning to commissioning to operation and maintenance [3].

2.1. Manufacturer specifics

If you just look at the manufacturers of industrial robots with the largest market shares, each one offers a proprietary programming language for implementing the program sequences. The following lists the manufacturer-specific languages of the five most common robot brands: Fanuc Karel / TP Yaskawa Inform ABB Rapid KUKA KRL Kawasaki AS-Language The syntax of these programming languages differs significantly in some cases. However, its basic features are based on high-level languages such as PASCAL or C2 and can be learned quickly if the user already knows other languages. However, the differences are not limited to the programming language used, but also to its configuration [4].

Specific operating systems on the robot controllers and configuration software tailored specifically to the user's own system hardly offer the potential to use synergies between different brands. The program code can therefore only be used across manufacturers after manual adaptation. This situation results in high barriers to switching if the use of a different brand should be advisable due to lower acquisition costs or other reasons. Apart from differences in the software, the various systems also differ in their hardware implementation. However, these differences are not part of the discussion here [5].

2.2. Overarching concepts

The fact that proprietary manufacturer-specific programming languages are based on existing high-level languages has led many manufacturers to develop SDKs (software development kits) to implement the underlying high-level languages themselves. These SDKs enable the user to write robot code in C, C++ or Java.In these cases, learning robot programming can build on existing programming knowledge. However, a manufacturer-specific development environment and a mostly slightly adapted syntax still represent significant differences between different brands [6].

2.3. Customer and supplier specifications

Aside from differences in the project planning software and programming languages provided by the manufacturer, both suppliers and end customers have their own standards for programming and commissioning robots. One of the best-known standards here is the Volkswagen Group's VASS standard. In a company with several thousand employees in production and maintenance as well as a large number of service providers, uniform guidelines are essential. Otherwise, an exchange of resources across departments or plant boundaries would be largely impossible. In addition to the VASS standard, which is binding for supplying plant engineers and programmers, many companies, including much smaller ones, have quasi-standards for the design of robot and control programs. Influenced by historically grown philosophies, these guidelines already differ in fundamental questions [9].

If a robot is used in conjunction with a programmable logic controller (PLC), there are different forms of distribution of intelligence between these two control units. A robot controller is able to take over control of a complete production cell. All logical operations are implemented in the robot's program code. In addition, the complete motion control is also processed in the same unit. In contrast to this philosophy, a PLC alternatively takes over control of all logical operations and only transmits target coordinates or trajectories to the robot as the command receiver. In this application, the robot controller only takes over the control of the axis drives. Aside from these two extremes, many individual intermediate solutions can be implemented. As can be seen in Figure 1, both the motion control and the program logic can take place either in the robot or in an outsourced intelligence, for example a PLC or a PC system [7].

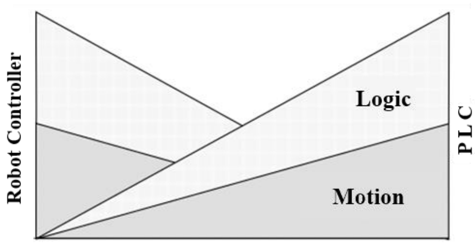

Figure 1. Distribution of intelligence between robot controller and PLC

2.4. Target groups

In industrial mass production, various activities are increasingly being carried out fully or partially automatically instead of exclusively by people. High repetition rates and consistent processes are predestined for the installation of robots.The system of robot manufacturers has also developed accordingly. High acquisition, commissioning and maintenance costs of n automated solution must always be taken into account (in addition to ethical concerns) when a robot is to be used for a task.These high entry barriers mean that robots are used largely in large-scale production, among other things. Consistent precision in monotonous activities is thus guaranteed. The advantages of the specific programming languages described in section 2.1. come into play particularly in systems with homogeneous structures, since the reusability of software created once is correspondingly high. A structure defined at the beginning or by a specification (see 2.3.) is used in an entire production line[8] .

2.5. Interval result

The developments on the part of robot manufacturers are strongly geared to market needs. According to Kinkel, however, no trend away from mass production is to be expected in future developments. Rather, an increase in the variety of variants, an increase in material complexity and increased requirements for manufacturing accuracy are emerging as factors. These new aspects will inevitably also have an influence on the way in which robots are integrated into an overall control unit. The following section discusses various reasons for new approaches to the topic that arise from the facts described in Chapter 2 [9].

III. ALTERNATIVE FOR NEW CONCEPTS

The manufacturing industry is subject to constant change. The Cluster of Excellence Integrative Production Technology for High-Wage Countries at RWTH Aachen University, for example, is conducting intensive research into factors that have a direct influence on production technology. Some of the research topics covered are directly related to the topic under consideration here. These include:

• Individualized production
• Hybrid production systems
• Self-optimizing production systems
• Integrated Technologies

In the following, specific reasons for a necessary adaptation of the existing concepts in the software-technical integration of industrial robots are worked out in more detail[10].

3.1. Variety of variants

As already indicated in section 2.5, many manufacturers offer their end customers the opportunity to personalize or individualize their end product. The automotive industry is an example of exponential growth in possible product variants. According to Burmann and Brettel, the trend is towards mass customization. Individualized end products have a direct impact on the manufacturing process, which is therefore also subject to individualization. According to Munz, flexibility in industrial production will be a decisive factor in the future. Increasing dynamics in the processes and a multiplication of the parts and materials used require adapted interaction models between higher-level controls and robots. According to Kinkel, an increase in product variance does not necessarily lead to a reduction in batch sizes. From this factor it can be concluded that new manufacturing systems must provide increased flexibility with the same throughput [11].

3.2. More complicated movement ranges, advanced manufacturing precision

The demands on the physical movement of a robot increase as components become more complex. At the same time, smaller manufacturing tolerances require increased precision in the execution of movements. According to the study by Sharif et al. current programming styles offer little scope for the implementation of complex movement sequences. In the future, various processes can be taken over by a robot, which in the past were carried out by production processes such as pressing, Punching or other processes designed for mass production have been implemented. To do this, it is sometimes necessary to create interfaces to various data sources in which information about the component properties is stored. Consistent data structures represent a relevant requirement that has become extremely important with the introduction of Industry 4.0 [12] .

3.3. Applying in SMEs and little serial

It was already made clear in section 2.4 that most robotics applications are tailored to processes with a high repetition factor in the processes to be carried out. Use in the production of small series or in individual production in small and medium-sized enterprises (SMEs) is less profitable due to high entry costs. In the case of SMEs, it is made more difficult that qualified personnel for maintenance and operation are not always available and have to be specially trained and assigned. According to Brettel et al., however, small and medium-sized enterprises in particular must react more dynamically to market needs. The introduction of automated solutions based on industrial robots still has enormous potential, particularly in areas of application with small batch sizes. To achieve this, complex systems must be accessible to less qualified personnel in the future.The result must be a move away from a robot as a special machine for defined application purposes towards a device for multiple applications [13] .

3.4. Demographic change and globalization

If one includes developing and emerging countries or countries with lower wage levels in the analysis of this paper, there are further factors to be taken into account. A lack of qualified personnel inevitably leads to the adaptation of the systems used. The learning curve for operating new systems must be flattened for less qualified workers. This applies both to highly industrialized countries such as Germany and to countries with less qualified workers. According to Ore et al., the existing problem of a lack of qualifications is exacerbated by demographic change in the industrialized nations. Based on the key findings of a study by the German Economic Institute on the skilled labor situation in Germany, it can be summarized that the market situation in 2017 is not yet critical. However, an aging workforce can be expected, although this varies from region to region. If the output of manufacturing companies remains the same or increases, a shrinking workforce or a lack of motivation to perform physically demanding activities can be compensated for by increasing the level of automation. Increasing productivity per job has already been observed in the past. In addition to the shortage of qualified workers, labor is becoming more expensive. Shorter product life cycles and a diversification of the product range mean that the workforce needs more training. In order to reduce the qualifications required for the operation of fully automated production systems with a high proportion of robots, the concepts currently in use must be evaluated and simplified [14] .

3.5. Interval result

A holistic consideration of the reasons for the necessary simplification of software concepts for robot integration would exceed the scope of this paper. The facts presented in this chapter only provide a brief overview of the most relevant points. However, it can be concluded that under certain circumstances the potential of industrial robots cannot be fully exploited in the future. In the following two chapters, current efforts and software solutions that have already been implemented are examined for their future applications [15].

IV. DEFECTS IN PROGRAMMING TOUCHS

The efforts to explore alternative programming approaches increased with the development of new fields of application for the use of industrial robots. Since the existing programming structures were largely tailored to the target groups described in section 2.4, industry-specific individual solutions were developed in order to serve new fields of use in a meaningful way. According to Sharif et al. The mechanical requirements for a robot are almost the same in both mass production and highly individual applications - such as research. However, the software mechanisms required differ, since as batch sizes decrease (up to the production of individual pieces), the flexibility in adapting programs must increase. Since the robot manufacturers themselves have only created limited opportunities to program movement sequences intuitively, the users themselves have developed various tools. However, all of the methods described below are based on a similar system. An interface layer is created between the robot controller and an external processing unit (PLC, PC system). This offers the software developer the opportunity to develop applications independently of the manufacturer's proprietary software environment. The interfaces shown in Figure 2.

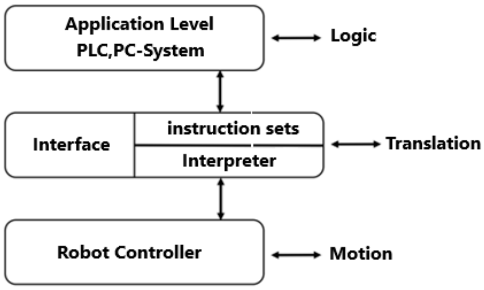

Figure 2. Interface level (middleware) between proprietary robot software and user program

The interface level shown in Figure 2, also referred to as middleware, is intended to reduce the complexity of the application software to be created or to map it to a system that is easier for the end user to learn. Program processing and motion control no longer take place on the robot controller, but are outsourced to the respective user program. Mastering the manufacturer-specific language syntax and adhering to specified programming paradigms is no longer necessary. This chapter examines some approaches that use the methodology described above as a basis. The need to simplify existing programming systems was formulated by Neto in 2010. Classic programming is too time-consuming and requires trained personnel. Abstracting complex programming languages results in the development of new fields of application, particularly in small and medium-sized companies [16].

4.1. PLC open - Coordinated Movement

The PLC open organization is driving the cross-manufacturer standardization of software in the field of control technology. In 2001, the Motion Control Library (Part 1) was published, in which function blocks for the operation of single-axis drives were published. The motivation for standardizing drive functions presented in the technical specification has lost none of its relevance today. Due to the following points, standardization of drive control must be promoted in order to make incompatible products and solutions between different manufacturers more usable:

• High costs due to necessary training and complicated engineering in different systems
• No reusability of applications due to non-uniform interfaces
• Hardware-specific application development

The specification expressly places emphasis on the reusability of developed solutions and increasing flexibility. However, this may be offset by a reduction in performance that comes with programming that is remote from the hardware. It can be assumed that machine-level programming will continue to be used for highly time-critical applications in order to fully exploit the technical possibilities, if the underlying process requires it. The Motion Control Specification Part 1 only defines blocks for controlling individual axes or for synchronizing multiple axes (gear synchronization). It is not possible to link multiple axes to implement resulting movements in space. This requirement was later added in another specification. The Motion Control Part 4 (Coordinated Motion) specification, published in 2008, expands the existing list to include commands for using multiple axes in multi-dimensional motion applications. This enables existing robotics and CNC applications to be mapped in a PLC environment using standardized function blocks. Some functions that were available in the robot controller now require implementation in the program of theexternal control to map the existing range of functions of industrial robots: Introduction of multidimensional coordinate systems Grouping of several axes into functionally dependent units Buffer mechanisms for smoothing sequential motion requirements The mxAutomation solution from robot manufacturer Kuka presented in section 4.3 was certified for the first time in 2016 according to the PLC open Motion Control Part 4 specification.5 At the time, a further nine manufacturers are approved by the PLCopen organization according to the Coordinated Motion specification.6 Especially for manufacturers with small market shares, standardization opens up the opportunity to new customers, as the barriers to change are significantly lower due to proprietary programming languages that no longer need to be learned [17].

4.2. KUKA|prc

Aside from the use of industrial robots in manufacturing companies, there have been efforts to use robots in other areas. Above all in the areas of architecture, art and design. The focus in these applications is different from that in industrial mass production. Other mechanisms are required for the visualization of prototypes or the creation of individual pieces. The quick and easy conversion of CAD models into physical bodies had a significant influence on the development of Kuka Parametric Robot Control (Kuka|prc). The creation of three-dimensional models, the definition of the robot movement and the simulation are implemented in a software environment. Kuka|prc corresponds to a middleware as shown in Fig.2. for the abstraction of complex programming syntax, but does not meet the requirements of the PLCopen specification. CAD data is only compiled from a design environment in order to output program code to the user in KRL. This can then be processed on a Kuka robot.

There are no cross-manufacturer approaches. This type of offline programming offers no scope for direct influence on the process or the processing of feedback during processing. Between the creation and execution of the software, the robot program is always compiled and transferred. This solution is already suitable for applications in small and medium-sized companies and for the production of small series. However, the user group is limited due to the CAD software used, Rhinoceros 3D, as this is primarily used in the field of design [18].

4.3. mxAutomation

With the mxAutomation library, Kuka provides a range of functions for cross-manufacturer use. Due to the use of powerful, real-time capable bus systems for communication between the controller and the robot controller, highly dynamic applications can be implemented. An adaptation kit provided enables other third-party manufacturers to use additional programming languages for the mxAutomation interface after agreement with Kuka.The integration of high-level languages such as C# or C++ makes it possible to write hardware-independent user programs that are processed on a PC or embedded controller. A buffer functionality implemented in the range of functions of mxAutomation enables the use of non-real-time capable controllers or communication channels. This buffering and the interpretation of the instructions transmitted by a controller takes place in the robot controller itself. Less powerful, non-deterministic communication methods such as UDP can therefore be used. Based on the architecture shown in Fig.3, it can be seen that the program scope in the robot controller is reduced to a minimum. The mx Automation server only interprets the motion commands of the motion instructions called in the user program.

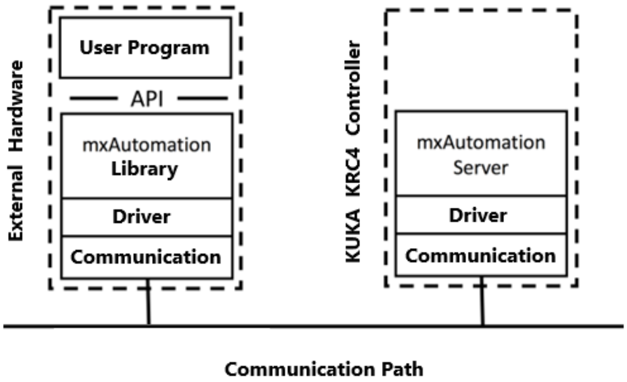

Figure 3. Functionality of the mxAutomation library

This architecture gives the user a lot of room to design the software or to select a software environment that seems most suitable for solving given problems. Contrary to Kuka's proprietary programming paradigms, the user is now able to generate robot programs dynamically at runtime or have them generated by algorithms. New possibilities are also opening up when designing the human-machine interface (HMI). This can be abstracted as required, taking into account the operator's qualifications [19].

4.4. Interval result

The solutions presented in this chapter represent only a small part of the systems available on the market. In the context of this elaboration, the further consideration of possible applications is based on the mxAutomation system provided by Kuka. This primarily serves the requirements in the industrial environment. The standardization of the interface between the controller and the robot and the opening up to new concepts of application development offer further possibilities beyond the Kuka solution. A higher level of abstraction enables new user groups to use robots for their applications. By simplifying operation and providing predefined functions (skills), this enables even less qualified end users to use it without the prior development of specific software tailored to the process. The method of programming by guideline described by Pan et al. appeals to users who only have knowledge of the process and the basic functionality of a robot. Due to a lack of programming knowledge, this user group would not be able to automate tasks independently using robots without simplified tools [20].

V. POTENTIAL APPLICATION CASES

The following looks at some application scenarios in which the use of the approaches presented in Chapter 4 either simplifies the engineering process or enables the implementation of the process with the help of robots.

5.1. Architectural modeling and prototype production

The Kuka|prc software presented in Section 4.2 already serves some requirements in the area of individual model design. The variety of 3D CAD design programs is large, so that interface standardization does not only have to take place on the robotics side. Kuka|prc already has a connection to the mxAutomation interface. Due to complex shapes, the requirements for model production are characterized by a large amount of movement and position data. Implementing such movements using the classic KRL programming language (or proprietary programming languages of other manufacturers) is inefficient. Kuka has addressed this problem itself and, with KUKA.CNC, has provided its own solution to use extensive CAD data as a basis for robot movement. The aim, however, must be to use the CAD data from the original project planning environment without first porting it to a different syntax. Production by robots offers new alternatives, particularly for models that can no longer be manufactured in 3D printers due to their size[21] .

5.2. Contour tracking

The post-processing of components with complex shapes represents a particular challenge. If this is increasingly carried out by experienced workers, new, automated processes are necessary due to the issue described in section 3.4. According to Sugita and Pan, current teaching processes using manufacturer-specific input devices are too inefficient for programming complex paths. Increasingly high precision requirements cannot be achieved by a manual teaching process. [Direct adoption of movement paths based on existing CAD data would be effective. Any necessary adjustment of the robot program due to a change in the shape of the component therefore no longer has to be carried out manually. Due to the use of robots instead of using traditional methods, economic advantages can be achieved in the following cases[22]:

- Removal of punch burrs
- Cutting processes (water cutting, plasma cutting)
- Blasting processes (sandblasting, dry ice blasting)
- Surface finishing (grinding, polishing)

5.3. Casting applications

For processes in which hot media are poured into molds, the connection of the control level with the CAD level and the resulting movement control of a robot offer decisive advantages. In order to obtain an optimal cast product, laminar filling of the mold and a temperature balance appropriate to solidification when pouring in the metal must be ensured. These factors could be significantly influenced by the introduction of tilt casting as a process method in which the mold is moved during the filling process. Tilt casting systems currently available on the market are largely limited to movement around a tilt axis. A robot-assisted casting process offers the possibility of moving a casting mold in three axes and in three dimensions during the casting process. Complex and flexible motion sequences are intensively analyzed and optimized in casting process simulations beforehand. An interface between the simulation environment and the robot's motion control leads to extremely short implementation times. By making the casting process more dynamic, the physical properties of the cast part can be significantly improved. More cost-intensive casting processes (die casting, low-pressure casting) can be replaced by a robot-assisted casting process, which results in a significant reduction in costs [23] .

5.4. Small series, SMEs

As explained in section 3.3, the entry barriers for the use of robots are currently often too high for small and medium-sized companies. The situation is similar when implementing processes with small batch sizes in large companies. Here, the ratio between programming time and cycle time is not profitable. Assuming that the processes themselves remain unchanged, the design and commissioning of a robot-based solution must be simplified. A sensor-basedOnline programming, in which the user actively moves the robot along the path it is to travel, is a first approach to an intuitive method. However, this method is only possible with collaborative robots (CoBots), which serve a very limited area of application due to a maximum payload of 35 kg.10 The range of specific application scenarios for robots in small and medium-sized businesses is extremely large. Any activity that has to be carried out several times or that requires increased precision can basically be taken over by a robot [24].

VI. DISCUSSION

The potential for the solutions presented in this paper goes far beyond the currently advertised fields of application for industrial robots. However, the many individual, sometimes historically grown approaches to the topic that are cultivated in companies must always be taken into account. Every change requires the acceptance of the workforce and further training in dealing with new processes. Simplifying the handling of robots results in a lower need for training or a reduced need for qualified personnel. This is also a certain necessity due to the statements made in Section 3.4. A robot provides assistance with a technological process or takes over it entirely. Whether a human worker is supplemented or replaced by a robot is not only an economic question. Ethical and work-physiological aspects also influence the decision-making process. Two fundamental ways of thinking come together here.

Is a human being replaced by a robot because a machine works more cost-efficiently in the long term or is a human being supported and relieved in his work in order to make the job more attractive? Regardless of this, an interface between humans and machines will continue to exist for the foreseeable future. The results of this elaboration only reveal a general trend towards simplification. A large number of manufacturers and products also require a large number of trained specialists. If there is a shortage of suitable personnel, standardization and generalization of the solutions used can maintain the competitiveness of companies. In order to test the viability of the statements made in this paper, solutions implemented in the future must be evaluated. It is not expected that the concepts of existing systems will be redesigned if this does not bring significant advantages. At this point in time, it is not possible to estimate which industries will benefit to what extent from the solutions presented here.

VII. SUMMARY

The need to adapt existing concepts of robot programming arises from the opening up to new user groups and the development of further technicalApplication areas. Both are not or only inadequately feasible under the existing programming paradigms. Application development must be adapted to the target groups. A technically experienced user must be able to implement a complex application previously implemented elsewhere using a robot. A less qualified user, on the other hand, will use the robot as an aid to quickly automate simple tasks. Since specific knowledge of application development is still required to use the mxAutomation library or other solutions discussed here, robots will only be used to a limited extent in small companies under these conditions.

Training staff would not be profitable. Therefore, the operation of a robot must be simplified so much that it can be learned just as quickly as a smartphone or other end device. Program developers who specialize in the middleware discussed here will expand the market for new applications and new user groups in the future. The requirements here are diverse. They range from the processing of large amounts of data (modeling, CAD/CAM) to the development of understandable, intuitively operated human-machine interfaces.

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