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Modern Industrial Robotics Industry

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Abstract*—*The purpose of article is to consider possibilities for use of industrial robots in modern production, task of study is to review current state of their application. The considered "novelties" of industrial robots from global trend manufacturers: powerful robot M-1000iA and small robot LR-10iA/10 from Fanuc; Yaskawa GP 215; ready2_spray from KUKA and short comparison of robots basic capabilities these three companies is provided. The paper presents extended classification of PR. In course of analysis in modern IR field, main trends in development of industrial robotics are highlighted.

Keywords—modern; robotics; industrial robotics; robot.

1. INTRODUCTION

Industrial robotics is widely used in many modern industries [1]-[8]. These robots are often used for repetitive tasks with high precision, replacing or maintaining hazardous workplaces or performing heavy work.

Industrial robots (IR) open up possibilities for automation in areas where it has not been possible or costly until now, for example in production of products in small and small series. Today robots are involved in production of robotic taxis, etc.

Modern industrial robotics makes it possible to improve already known technological and production processes, to improve quality of finished products.

IRs can independently work with tools, blanks and materials for automation of main and auxiliary production processes, since modern IRs are smarter and more versatile than their predecessors [5]. They can shorten production cycles and optimize resource use.

Today, manufacturers can start day with few robots, doing same job and then end day with same robots, doing very different set of tasks. This adaptability makes IRs useful in low volume production with wide variety of tasks.

Every year demand for such "technical cell" as IR is increasing.

According to information from International Federation of Robotics, 3 million industrial robots working in factories around world demonstrate increase in demand by 10% [9]. Despite global pandemic, sales of new robots grew slightly by 0.5 %, with 384,000 units shipped worldwide in 2020.

The Japanese robotics market is expected to grow 5 % in 2022.

IRs will become main automation tools with great economic impact. Investment expectations in IR are high – 88 % of respondents expect an increase in investment, which is in line with IFR statistics in recent years. The growth of investments in various industries is mainly due to goal of reducing production costs. Investment is also motivated by need for increased manufacturing flexibility and improved robotic capabilities. It is also important to use modern methods and approaches for the analysis of phenomena, data, and events [10]-[15]. As a result, topic of work is relevant.

2. RELATED WORK

A sufficient number of works have been devoted to application of industrial robots industry today, which is explained by constant interest of this area [16].

Modern industrial robots are widely used in many production lines.

In [17], studies are directed to use of industrial robots in automated control.

The use of industrial robots in technological line for production of mechanical parts is described in [18].

Automation of welding process by use of industrial robots in [19].

In [20], overview and classification of such robots as: industrial robots, autonomous mobile robots, humanoid robots and educational robots is given in detail. The authors mentioned those pro-industrial robots that work in well-defined conditions on production tasks.

The choice of industrial robots for milling work is described in [21].

The classification of IR is presented in [22], where authors identified t following groups of IR: robots to reduce reject, robots to reduce man-hour costs; robots to improve quality; robots to reduce production time; robots to increase danger in using raw materials.

The classification of industrial robots by number of movable-structural synthesis degrees and useful configurations is described in [23].

The design features of industrial robots are widely presented in works of authors [24]-[28].

In [27], authors considered the problem of optimizing design of industrial robot manipulator to minimize excess weight.

The peculiarity of work [28] is that authors reviewed solutions to issue of fingers design automation for gripping industrial robots.

Work [29] presents trends in smart manufacturing: role of humans and industrial robots in smart factories.

The review given in [30] is devoted to promising applications of robotic technologies in industrial field. Robotic solutions in areas with non-intensive applications are presented, and their implementations are analyzed.

3. Overview of Modern Industrial Robotics Industry

There are number of reasons why there is growing need to develop IR.

The most important motive is – robotic production, which incur minimal losses, while robotic factories can be controlled remotely using information technology [16].

Almost all large and trendy production facilities are equipped with industrial robots.

For example, annual installations of industrial robots 2015-2020 and 2021* -2024* World Robotics (table 1) [9].

Table 1. Annual installations of industrial robots 2015-2020 and 2021*-2024*

year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Units	254	304	400	422	382	384	435	453	486	518

The smartest factory automation that shook world is Chinese home appliance manufacturer's smart factory Galanz's, which is fully automated. Such a plant has 4 “smart” production lines and each of them is equipped with 17 mechanical arms (fig. 1) [31]-[33]. The robotic arms are responsible for manufacturing, including material input, handling, and assembly. Integrated production system, automated by machine tools and computers. Various advanced technologies are connected. Industrial automation refers to system in which many jobs have been performed before. However, as online and offline information mixes, and information about producers and consumers is linked to each other, industrial automation has evolved based on market forecasts as well as demand.

Figure 1. Galanz's Smart Factory

IR is necessary element for areas of automation.

IR is core of industrial automation.

Consider latest IR models.

FANUC provides some of most advanced industrial automation solutions available, so let's start by looking at M-1000iA heavy-duty robot. The robot was demonstrated at EMO exhibition in Milan (fig. 2, a) [34], [35]. Of particular note, M-1000iA is largest FANUC robot.

a) b)

Figure 2. Innovations in industrial robotics: a) powerful robot M-1000iA; b) small robot LR-10iA/10

Has a 1000 kg wrist payload and maximum reach of 3253 mm.

This IR is equipped with serial link mechanism rather than parallel link mechanism typical of heavy payload robots. As result, M-1000iA has wider range of motion in both vertical and longitudinal directions, allowing arm to stand upright and pivot backward, which is not possible with parallel link robots. This capability provides users with enhanced versatility in wide variety of processing applications.

The M-1000iA IR can automate production lines and improve productivity in areas such as drilling and machining of automotive components, building materials and batteries for electric vehicles [34], [35].

In particular, robot features high rigidity and high wrist performance while intuitive and easy-to-use tablet is also available.

In order to increase flexibility of its application, M-1000iA can be configured with vision sensors and wide range of intelligent functions.

Another advantage of M-1000iA is its flip capability. This feature allows users to create more compact and flexible production cells and helps to reduce cycle times by reducing travel distances [34], [35].

Next, consider a new addition to series of small industrial robots LR-10iA / 10 (fig. 2, b).

FANUC America has released brand new LR-10iA / 10 robot for equipment maintenance, assembly, dispensing and packaging.

The arm weighs 46 kg and can be installed on floor, ceiling or even at angle.

In order to expand functionality of LR-10iA/10, it can be installed on mobile platform. FANUC will begin shipping brand new LR-10iA/10 in January 2022.

The LR-10iA/10 has payload of 10 kg and reach of 1101 mm [36].

The closed design of device includes built-in air ducts, solenoid valves and electrical networks. The IP67 rating allows it to operate in industrial environments with dust, water and oil.

Equipped with FANUC R-30iB Mate Plus controller, LR-10iA/10 offers integrated iRVision and zero downtime (ZDT). ZDT reduces unexpected shutdowns, helps users maximize productivity, optimize maintenance costs, extend life of their robots, and access data from anywhere through ZDT web portal [36].

Now we present an overview of robots from Yaskawa – industrial robot industry of Japanese company Yaskawa Electric Corporation.

The Yaskawa model range includes more than 150 articulated, delta and scara robots, as well as complete robotic lines, including industrial robots, technological equipment and safety devices [37], [38].

As example, latest innovations are 6-axis innovative high-speed robot palletizer Yaskawa GP 215 with lifting capacity of 215 kg (fig. 3, a) [37], [38].

IR weight 1340 kg. The cell robot is designed for palletizing corrugated boxes with finished products. Also ideal for applications such as machine and press maintenance, heavy assembly operations, bulk packaging. Installation of this robot is only floor-standing.

The robot is equipped with an SPZ vacuum gripper for layer of products and cardboard interlayer sheets manufactured by Schmalz (Germany).

a) b)

Figure 3. Innovative IR: a) Yaskawa GP 215; b) Painting robot ready2_spray

And another example would be installation from largest German manufacturer – KUKA, which has 25 subsidiaries in Australia, Brazil, Canada, China, Mexico, USA, Taiwan, Japan, etc.

KUKA is one of three largest suppliers of IR for automotive industry in global market and leading supplier in European market.

For every task, KUKA offers right industrial robot – with different load capacities, reach and special designs.

Let us consider installation with IR for painting ready2_spray from KUKA company (fig. 3, b), mass without a controller is 54 kilograms [39], [40].

The KUKA ready2_spray painting robot is primarily intended for applications in which highest paintwork requirements are imposed and where technological solutions with integrated explosion protection are decisive. This installation has already been classified as best-in-class robotic solution.

KUKA ready2_spray components:

1. Robot KR 10 R1100 EX 2G from KR AGILUS sixx series (it is six-axis robot withmaximum reach of 1100 mm and load capacity of up to 10 kg).

2. Dürr 1K / 2K paint application application.

3. KUKA KR C4 control unit in combination with Dürr EcoAUC control unit.

That is, KUKA has created new ready2_use packages – preconfigured, coordinated application packages that are assembled, documented and tested. These solutions can be easily and quickly integrated into production equipment.

Packages: ready2_arc (for welding); ready2_educater (cell for studying robot is complete starter package for acquiring basic knowledge of robotics); ready2_pilot (to control the robot manually using 6D mouse); ready2_rivet (for self-piercing rivet); ready2_spot (for spot welding) [41].

So, if we draw parallels on most frequently performed IR work from companies that are leaders in IRs production, results are presented in table 2.

Table 2. IR opportunities from companies: FANUC, KUKA, Yaskawa

Name	FANUC	KUKA	Yaskawa
Serve machine tools	+	+	+
Quality control	+	+	+
Casting	+	+	+
Forging and stamping	+	+	+
Welding	+	+	+
Spray coating	+	+	+
Moving materials	+	+	+
Assembling parts	+	+	+
Palletizing	+	+	+

As can be seen from table 2, all companies perform most common technological processes.

4. FEATURES OF INDUSTRIAL ROBOTS

Modern production is hard to imagine without automation and industrial robots. An industrial robot is automatic, programmable, flexible multifunctional manipulator with adjustable movement along various axes, which, according to programs, moves materials, parts, tools and special equipment in operations, performing many tasks.

Most often it is equipped with one or more working arms, ending with hinge.

IR has various designs and technical characteristics that determine their technological capabilities and applications. Let's propose classification of IR in table 3.

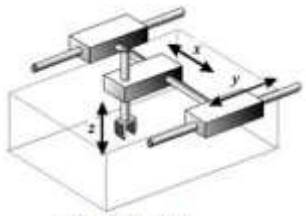
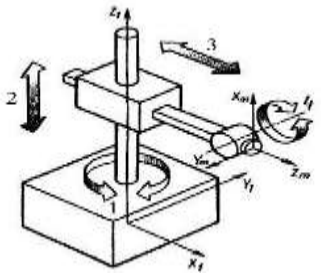
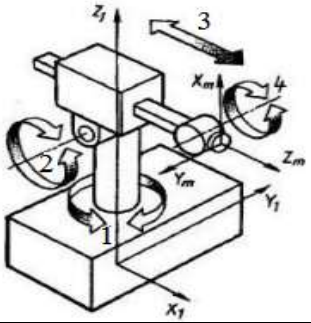
Table 3. Classification of modern IR

№	Feature name	Peculiarities				
1	2	3				
1	Degree of specialization	Special – perform one technological operation or are used to work with certain type of parts. Their carrying capacity lies in range of 5 ... 500 kg.				
		Specialized – perform technological operations of any kind, for example, for stacking, servicing automated warehouses, sampling and nesting of parts oriented in special container, etc. The carrying capacity of such robots is usually in range of 2.5 ... 500 kg.				
		Target – perform one or several operations, but can serve wide range of machines, perform actions of similar nature associated with manipulation of work piece and processed part. The carrying capacity of such robots usually lies in range of 20 ... 250 kg.				
		Universal (multipurpose) – for servicing equipment for various technological purposes, with difference that it may require variety of techniques when performing maintenance operations. The carrying capacity of such robots lies in range of 2,5 ... 40 kg.				
2	By type of production	CT	MP	FP	WD	CN
		TSW	HT	CMP	AS	PPL
		PP	PLC	ML	ME and other	
3	Mobility	Stationary			Mobile	
4	By design	Built in equipment				
		Suspended				
		Floor				

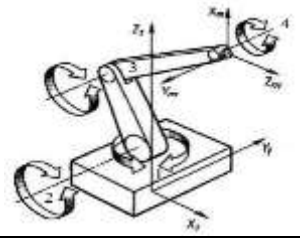
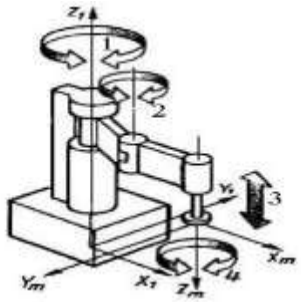
Continuation of table 3.

1	2	3
5	By type of control	Semi-autonomous – they act strictly according to given program, often they are not able to independently correct their actions, do not have sensors and cannot do without the participation of an operator.
		Fully autonomous – they perform programmed actions without participation of operator. According to given algorithms, they can adjust their actions as necessary. Usually, such works completely cover field of activity on their section of conveyor, without involvement of manpower.
6	By level of information entered and method of training	Non-reprogrammable (non-learning) – IRs with rigid cycle of operations are equipped with sufficiently simple program prepared in advance that repeats same predetermined sequence of operations regardless of changing conditions and cannot be changed by simple means.
		Rigid programmable (retraining) – IRs with variable cycle of operations contain complete set of information that does not change during work itself, but amenable to correction by "retraining" when changing (readjusting) technological process.
		Reprogrammable (trainable) – IRs with variable cycle of operations, along with full set of program information, have sensor support and feedback.
		Flexible-programmable (self-learning) – IRs with elements of artificial intelligence, in addition to developed sensory system in form of artificial organs of vision, hearing, touch and others, must have powerful information and control system and perfect algorithmic and software.
7	Type of drive	Electric
		Hydraulic
		Pneumatic
		Pneumo-hydraulic
8	On speed of robots for general use	Small – at linear velocities for individual degrees of mobility up to 0,5 m / s.
		Average – at linear speeds over 0,5 to 1 m / s.
		High – at linear speeds over 1 m / s.
9	By accuracy of robots for general use	Small – with linear error of 1 mm and more.
		Average – with linear error from 0,1 to 1 mm.
		High – with linear error of less than 0,1 mm.
10	By number of manipulators	One-manipulator (one-handed)
		Two-handed
		Three-armed
		Four-armed
11	By carrying capacity	Ultralight – up to 1 kg
		Lightweight – up to 10 kg
		Medium – up to 100 kg
		Heavy – up to 1000 kg
		Super heavy – over 1000 kg
12	By type of basic coordinate system of IR manipulator	In rectangular, or Cartesian, coordinate system. Has three translational basic degrees of mobility with mutually perpendicular directions of displacement. Cartesian robots, also called gantry robots. These robots are rectangular in shape. These types of IR have three prismatic joints to provide linear movement, sliding along its three perpendicular axes. They can also have wrist attached to allow rotational motion [16]. Cartesian robots are used for: loading and unloading; processing of materials; assembly and disassembly; reprocessing of nuclear materials; adhesive applications.

Continuation of table 3.

1	2	3
12	By type of basic coordinate system of IR manipulator	Cartesian robots are used in most industrial tasks because they offer flexibility in their configuration, which makes them suitable for specific application needs [17].  Cartesian Robot
		In cylindrical coordinate system. It has one rotational and two translational basic degrees of mobility with mutually perpendicular directions of movement. Cylindrical robots have cylindrical work area with pivoting shaft and retractable arm that moves vertically and slides. Cylinder works are used for: injection molding; loading and unloading machines; coating. 
		In spherical, or polar, coordinate system, it has two rotational mutually perpendicular and translational degrees of mobility. They are stationary robotic arms. Thus, these robots are more complex than Cartesian and cylindrical robots, while control solutions are less complex than articulated robot devices. Such IRs has only swivel joints. These are some of first robots to be used in industry. They are commonly used for machine maintenance in injection molding, plastic injection molding and extrusion, as well as welding. 

Continuation of table 3.

1	2	3
12	By type of basic coordinate system of IR manipulator	In an angular, or angular, spherical coordinate system, it has three rotational basic degrees of mobility. This configuration of manipulator, also called complex spherical, or anthropomorphic, consists of links that can rotate like a human hand. 
		In an angular cylindrical, or complex cylindrical, coordinate system, it has two degrees of mobility that are rotational in horizontal plane and translational degree perpendicular to it, i.e. directed vertically. 
13	By nature of programming of speeds and discreteness of movements	Positional program control system – moving from point to point.
		Contour program control system – along continuous trajectory.

Note: CT – casting; MP – mechanical processing; FP – press-forging; WD – welding (all types of welding: arc and contact); CN – coating; HT – heat treatment; TSW – transport and storage works; CMP – control and measurement processes; AS – assembly; PPL – packing, packing and distribution, palletizing; PLC – plasma and laser cutting; ML – milling; ME – mechanical engineering.

Thus, we have seen main trends in development of industrial robotics:

1. Safe collaborative robots (cobots). Traditional industrial robots are most commonly used in automotive industry, where robots stand behind conveyor and are configured to perform single task. Cobots are highly productive. Cobots are easily reconfigured to perform other scenarios and solve new production tasks, which were generally performed by operators directly in production.

2. Cybersecurity. The main reason for relevance is information environment of enterprise in which robot works is not always safe, since sometimes works are directly connected to Internet, for example, to update firmware from manufacturer. And internal IT environment of enterprise itself is not always sufficiently protected. Therefore, there is trend in development of cybersecurity.

3. Machine vision, since for IRs, which are used in conveyor production, in order to move workpieces, high positioning accuracy is required – it is not always possible. As consequence, reason for relevance of machine vision development. The digital camera receives an image of workpiece in working area of robot, software analyzes it, formulates task before work, and robot performs them. Tasks that can be solved using machine vision: control of product assembly process, counting objects, measuring their parameters, etc.

4. Technologies of artificial intelligence and machine learning. Industrial work is constantly striving to become smarter, more accurate, faster and therefore find new areas of application. Such robotics has high degree of autonomy, recognition of environmental changes, and variability in responses to these changes.

5. CONCLUSION

The purpose of article is to consider possibilities for use of industrial robots in modern production, task of study is to review current state of their application.

Thus, having considered some types of innovative industrial robots, we can say that robots are mainly engaged in heavy and dangerous work, can lead to significant reduction in employment in individual factories and decrease in number of injuries in workplace.

The considered "novelties" of industrial robots from global trend manufacturers: powerful robot M-1000iA and small robot LR-10iA/10 from Fanuc; Yaskawa GP 215; ready2_spray from KUKA. A comparison of their main features is briefly given.

The paper presents extended classification of IR. In course of analysis in field of modern IR, main trends in development of industrial robotics are highlighted.

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