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Industry 4.0 – Robots with Distributed Mobility and Elements of AI

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D. Avishay [α], V. Pavlov [σ], G. Pavlova [ρ], B. Petrov [Ѡ] & N. Dimitrov [¥]

Abstract- **Robots artificial intelligence elements, which are a product and means of the Fourth Industrial Revolution, are a factor in the future development of the world's society. The present article proposes building a strategy for the future development of robotics by laying the principle of appropriately distributed mobility and functionality based and corresponding artificial intelligence. This principle corresponds to the millennial history of the Earth living beings evolution. The autors introduce new concepts such as kinematic, technological (professional) and structural-functional intelligence. It analyzes the connectivity of the internet, cyber-physical systems. There are three approaches proposed for design development: biological, engineering (industrial) and hybrid.**

I. Introduction

The many traits characterize the Fourth Industrial Revolution. The most significant of them is the massive transfer of intellectual activity and decision making toward the information systems. "Machine to Machine" communication (M2M) becomes increasingly desirable. Humans reduce their physical and mental activity in the industry. Most functions of the man are monitoring, logistic and maintenance activities, as well as high-level management [1, 2]. In this connection, the global network represented by the Internet of Things (IoT) plays a significant role. The global wireless network allows "smart" devices to connect to each other and be remotely controlled by a set of rules beforehand installed into a controller. Another significant feature of the Fourth Industrial Revolution (Industry 4.0) is the structural and functional flexibility of production, which contributes the collaborative work of robots with Humans in one job (work position). This collaboration also increases the flexibility in organizing the technological sequence in production.

The robot is one of the tools that support human activity in the modern industry inside of it (implementation of the auxiliary, technological and transport operations) and outside of it (investigation of the surrounding environment, space research, medicine, military action, etc.). If we consider the robot as "smart" device and make an analogy between robot and human brain, then only the short-term memory will remain in the robot's physical body, and the contextual dependence of memory and long-lasting memory itself will be exported to a cloud environment. The short memory will provide the robot's functionality, its collaboration, and continuation of the operation in case of a longer cut off of the cloud services. The more "intelligent" the robot is concerning its decision capabilities, the more cloud power will be needed to perform complex computational tasks such as image processing, voice recognition, data comparison and making high latency decisions. Information about current states of the system obtained by various sensors needs to be saved in the cloud continuously. The unified system controls the rational application of a certain logic and how to use the reserves with greater precision. Cyber-Physical Systems (CPS) play a significant role in this direction. Although these generalized activities are exported „out" of the objects, robots need sufficient movement and intelligent behavior to perform their functional tasks qualitatively.

The question arises on how to create a robot that meets these conditions and has sufficient kinematic, communicative and intellectual capabilities. Nature, in that perspective, is an inexhaustible source from which humankind has gained experience and knowledge for its development. It is entirely possible that the principles sought are set in the organs and actions of humans and animals. For a person, the presence of (natural) intellect to a different degree is acceptable. In other living beings, even at the lowest level, functions like nutrition, survival and reproduction, are ensured by the necessary intellect level. Copying of Nature is a direction for the development of Biological Inspired Robots, whose achievements at this point are modest, both in terms of kinematic and intellectual capabilities.

The movement is an important factor for biological individuals in search of food and survival. The control of kinematic and dynamic movement is enshrined in robotics before the advent of the microprocessor control (electronic age of robotics), of course with insufficient quantity and quality. The second characteristic – intellect in technique could be replaced by artificial intelligence (AI), and it has significant achievements but is still not enough developed. It is noteworthy that the blasts of its application exceed the needs of robotics (R). The third component - "nutrition" - in the technique corresponds to the energy and the means for its transformation. For now, robotics rely heavily on electric one.

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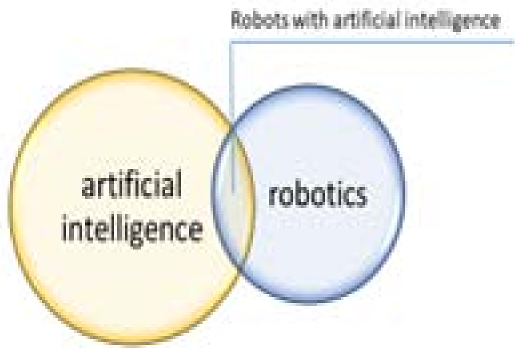
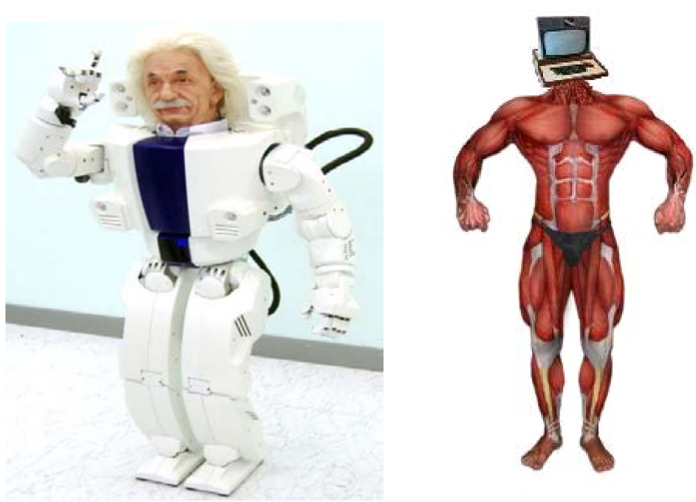


Fig. 1: Integration between artificial intelligence and robotics

Artificial intelligence is a broad concept and is used to solve a wide range of tasks. Robots, as a product and means of production, also perform a wide range of tasks with the necessary and sufficient requirements without the necessity of thinking and reasoning. The robot performs its task at the level of the intellect of the programming person with the constraints of a machine. It is not necessary everywhere and for all the robots to have "intelligence" to perform their tasks properly in production conditions. In Fig. 1 is shown the cross-section AI and R.

The section 'robots with artificial intelligence' is not homogenous. There is diversity in the combination of kinematic possibilities and intellect. This is clearly illustrated in living nature, but there are some examples in the industry. Figure 2 illustrates the border situations of integration between kinematic capabilities and AI. A very limited in kinematic abilities robot is equipped with an extremely intellectual "head" (Fig. 2a) [8]. A counter solution (Fig. 2b) is a body with high mobility and aesthetic appearance with a primitive computer illustrating low intellect. Obviously, at this stage, it is impossible and inappropriate to fully seek a complete engineering analogy with the biological. The question of modern robot design is to find out how many and how to allocate the degrees of freedom (active and passive) and according to the functional purpose to determine the necessary intellect. This approach excludes robots from fundamental research.



(a) (b)

Fig. 2: Nonconformity of integration between intlligence and motion avilities

a) Limited „mechanics "with super intelligence
b) Super „mechanics "with slimited intelligence

II. The Robot – Product and Means of Industry 4.0.

In science fiction novels (Karel Chapek, Isaac Asimov, etc.) the robot is described as a mean which replaces the man in hard and unattractive work (iron man). Of course, there have been other fantasies, but robotics would not get its prosperity unless it becomes an effective means of production. Even the first industrial applications of intelligent robots (UNIMATE, 1962, VERZATRAN, 1964) reveal the great possibilities of production automation. It is primarily due to the flexibility provided by microprocessor control. According to the authors of this study, this is defined as an "electronic era" in robotics. Very soon the robots ware applied in many other fields - medicine (surgery, rehabilitation, prosthesis), space and ocean exploration, military and police activities, etc.

All these robots carry the features of industrial ones, which do manipulations with material objects in a given place and move men to it. Industry robots, stationary or mobile, also require new abilities concerning motion as well as management and behavior capabilites. Robotic industries and robotic technologies give a new look to the industry. Logically, all the advances in engineering and technology at a current stage reflect in the robot's qualities, as they are an industrial product that integrates top scientific achievements. That is why a robot is a machine that looks for new, more rational tasks and ways for their intelligent performing.

In fact Industry 4.0 will change not only the production itself but also the products part of which are the robots, both for industrial and research applications. Those advanced machines can help companies accelerate the digital transformation needed to improve their productivity, innovation and quality by consistently lowering the operation and production costs. The new Industrial revolution relies highly on the digital connectivity between objects in the production plant and so-called digital twins. Those digital avatars and models will help design better and intelligent products, simulate their behavior prior production and analyze their lifecycle in a much more predictive manner. Data-driven design approach and the connectivity of the product with the manufacturer through its lifecycle will make the foundation of those insights the digital factories will consist of machines, robots and sensors so interconnected that they could "feel/predict" the future bottlenecks and failures. This is where the Internet of Things in manufacturing comes in place. The information generated by those interconnected devices will lead to a huge amount of data (Big Data) which should and must be managed.

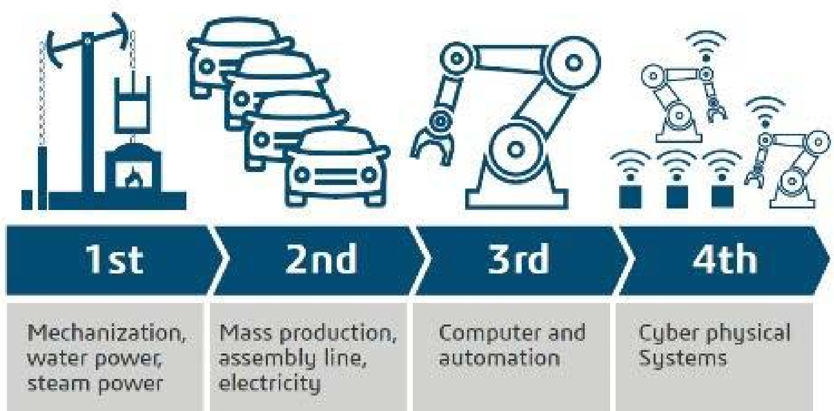


Fig. 3: Key technologies representing the industrial revolutions [9]

Based on the above-said robots will not only be part of the new industrial revolution but also they will be better in every aspect. Their design, connectivity, quality, processing and sensing will supersede everything so far because of the implementation of new technologies every day. The most interesting idea is that their intelligence will be adaptive based on the environment.

III. Robots with Elements of Artificial Intelligence

The integration between two relatively autonomous and dynamically developing areas - robotics and artificial intelligence, provokes new qualities and possibilities for application of robotised systems in production [3]. The role of the artificial intelligence in information processing and making adequate decisions from the robot's "sensory organs" (engineering analogs of the biologic species - vision, hearing, speech, smell, etc.), is especially crucial. Due to this integration will be created "thinking (smart)" robots, analogs of human [4,5] or other living beings.

The robots perform technological, support and transport operations in the industry, and that is why the requirements for intelligent behavior are limited. Together with the technological machinery, equipment, and other auxiliary equipment, they form the structural building of a production, which is subordinate to the type of organization, functional requirements for productivity and quality of the produced product. Three are qualities that distinguish industrial robots with artificial intelligence from conventional ones. They possess kinematic (intelligent movement), technological (intelligent action) and structural and functional (collaborative) intellect.

Therefore, hardware and software are needful for artificial intelligence at this stage for: robots movement (mostly auxiliary operations) with the necessary "kinematic intelligence" that optimizes movement in terms of the basic kinematic parameters -

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position, trajectory, velocity, acceleration and makes possible a Collaborative Work between robots, as well as between robots and people at one workplace without conflict situations. Robots which perform technological operations (welding, painting, cutting, etc.) must have "technological intelligence", i.e., to have the possibility to change their behavior with acceptable deviations in the technological conditions to keep the quality. In practice, the possibility of cognitive mutuality in the production of technological or auxiliary operations is stimulated. These capabilities allow concentration of operations at one workstation and this way the workspace could become smaller and transport time could be reduced, resulting in increased productivity and quality improvement. Kinematic Intelligence primarily associates with the use of "knowledge base". The task is solvable with the proper training of the robots and the people who will work together.

Development of robots with artificial intelligence, at the present stage, is characterized by one principle - "the more, so much more", i.e., more degrees of freedom and greater possibilities of artificial intelligence. However, the creation of a "super robot" that is applicable everywhere and for everything is not expedient and even is less effective.

IV. Robots with Appropriately Distributed Mobility and Corresponding Intelligence

a) Biological approach for robot design (Biological Inspired Robots)

Nature has created a wide variety of mobile creatures with great opportunities to move in an undefined environment on the surface of the earth, with the ability to overcome barriers of different character and location. The complete movement on the surface of the ground with the ability to overcome obstacles can achieve by a sufficient number and appropriately located controllable and passive (not controllable) degrees of freedom in the body. Such examples in nature are snakes and worms. The other extreme is the realization of complete movement through a sufficient number of limbs (feet) with necessary degrees of freedom, and the body is rigid (stationary) that does not change its shape during the movement. There are many examples of insects, turtles, and so on.

The most widespread in the living environment are the cases when the mobile creatures have mobility in the body that favors control behavior during the movement, overcoming and obstructing obstacles. The distribution of degrees of freedom between the body and extremities is biologically resolved in terms of the number, the location of the axes, the type of joints as well as concerning the functions of the relative displacement values. Here it is essential to pay attention to the spine and its extension (neck, tail), to the ends of the legs - grasping parts of the hands, foot of the feet. In these places are concentrated a large number of degrees of freedom (active and passive), specific joints and vertebrae, driving schemas, and use other features, but in modern robotics they are limited.

In the mobile robotics, the problem of the total number of degrees of freedom and their distribution between body and legs at this stage has no reasoned and functionally motivated solution. There is evidence of a minimum number of degrees of freedom for full movement in terms of the trajectory (geometry) of the displacement. The minimum number of active degrees of freedom is a prerequisite for the maximum energy efficiency of the robot in the currently used motor devices. The future development cannot be done only in this direction, as functional requirements are increasing.

But in the nearest future, it could not be possible to develop an algorithm that uniquely determines the total number of degrees of freedom of the robot and the way of their distribution between the body and the legs. For now, it is clear that the introduction of biological analogies should be functionally justified, while this can remain a subject of interest for research projects.

Another is the issue when it comes to the prosthesis. The achievements of robotics in prosthesis are not only for limbs and joints but also for other human organs.

b) Engineering (industrial) approach to design robots

This approach could be summed up as a search for a solution to perform one or a group of functional tasks with minimal but sufficient kinematic and intellectual capabilities which, under the same conditions, ensure low cost, energy consumption, reliability, and easy maintenance. It is known that the technique uses wheels, chains, cylindrical hinges and linear joints that have proven properties and have no analogs in animals. They are successfully applied to stationary and mobile robots. Wheels, chains, cylindrical hinges and linear joints, that have proven properties and do not have analog in animals, are successfully applied to stationary and mobile robots.

For industrial stationary robots, simple rotational and translational movements are used, which could be realized respectively in cylindrical and prismatic joints. The number and mutual arrangement of the axes are determined by the principles of complete translation and orientation of the manipulated objects. It is well known that three elementary moves are necessary for complete replacement and its combinations are: RRR, RRT, RTR, TRR, RTT, TRT, TTR, and TTT (R-rotation, T-linear translation).

Orientation is most often done by three rotations but replacing one of them with a translation for entering details into machine gripping devices. The use of more than six manageable degrees of freedom is related to serving more than one workstation and/or enhancing obstruction abilities. Wide is the number and combinations in capturing matte objects that are the ultimate effector of this class of robots. They range from one (a range of specialized grippers) to those of the human gripper (not only interesting for robots but also prosthetics).

Spherical hinges, knee and scissors are successfully fabricated and applied in prosthetics but are not used in robots yet, due to the difficult drive and control of a group of axles by conventional engines.

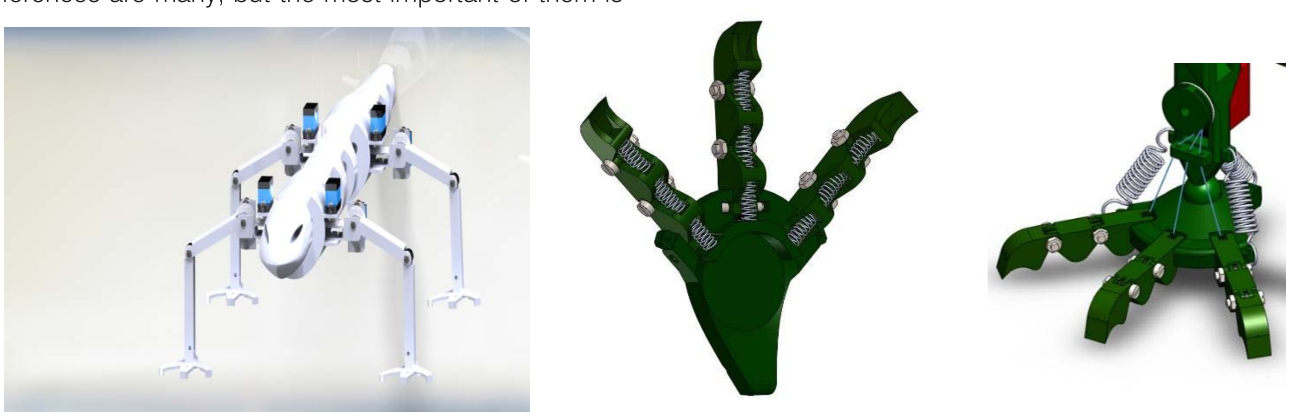
Using 3D technologies to create non-disassembled joints close to those of biological ones using two-component materials - one with a low friction coefficient - a cartilage analog and another one with high mechanical strength - a bone analogue will probably achieve significant novel results. The printing also allows execution as an assembled unit without using of additional fasteners. If applicable, individual vertebrae for operative replacement could be used. For robots, significant changes will occur when this technology combines with artificial muscles.

c) A hybrid approach

This design approach is applied nowadays but limited. And now, the industrial robotics searches for analogies with the human hands, and the walking robots - with legs of humans and other animals, but there is still more differences than a similarity to the original. The differences are many, but the most important of them is that the robots have a significantly smaller number of degrees of freedom. Today's design capabilities are compelled at every degree of freedom to provide the necessary drive (electric motors, power cylinders transmissions), which leads to a series of unfavorable problems.

A substantial reserve in this direction is in the combination of active (derived from controllable motors) and passive (translations caused by external force factors, most often realized through elastic deformations) degrees of freedom. The dependable movements, when one engine moves two or more units with a predefined ratio of the displacement, are also a reserve of increased mobility with a smaller number of motors.

One example [6], [7] of combining active and passive degrees of freedom into a lizard analog robot (Fig. 4.a) shows satisfactory results. The vertebral column has five vertebrae, the tail - three and the neck – two and each of them allows 4+2 (a little move along the horizontal axis and a little rotation along the vertical axis) 6 degrees of freedom. Passive movements caused by surface unevenness are realized at the expense of spring deformations, and the active movements (spine, tail and neck rotation relative to a vertical axis to realise a curve corresponding to the gait) are obtained from a controllable motor, located in the pelvis belt using threaded/wire mechanisms.



(a) (b)

Fig. 4: Mobile robot a lizard analog

a) general view b) adaptive foot

Each of the legs (Fig. 4.b) has two controllable and one dependable degree of freedom. The feet are connected to the last unit of the leg by a spherical joint and springs, and the three fingers have three cylindrical hinges that have a defined position by the springs. When the robot moves in uneven terrain they adapt to it, by improving the contact through a driven motor and wire mechanisms operating the motion of each of the "fingers".

Most of the details are made by 3D printing, which allows for much free of constraints design approach, although the elementary base (motors, springs, wire mechanisms, etc.) impose engineering design conditions and constraints. The application and development of the 3D technology and the specific element base for robots will be resulting in the creation of much more realistic biomimetic robots which will lead to changes in the design and engineering techniques.

V. Conclusion

The word robot begins to cover its true content, externally to look like to its prototype (human, animal, bird, etc.) and has the qualities to perceive, analyze and act according to the terms of reference and the specific conditions. External features are a product of development of technology and elementary basis, and behavior is formed by adequate discernment of the environment by methods and means of artificial intelligence. An essential milestone for effective development is the metering of the need for movement and intelligent behavior in performing certain tasks. Overdose of any of the two movements or intellect leads to low efficiency for the industry. Searching for the best match must be the basic rule for the development of science-applied projects.

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