ROBOTICS IN THE NEW ERA – CHALLENGES ON ROBOT DESIGN[⊗]

AZ ÚJ KORSZAK ROBOTIKÁJA - A ROBOT TERVEZÉS KIHÍVÁSAI

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Abstract: *The way robot design has evolved the recent years depends on their base design, with its strengths and flows as well as the need for use of them in new applications. A various number of factors can be investigated:*
- *The position of industrial robots in their natural Product Life Cycle.*
- *Innovations that drive new growth*
- *The need for flexibility and modularity*
- *Adaptation in sectors with high manual labor content*

Current approach and views toward robots and automation will provide the basis for future development of industrial robots and linked sectors such as aerospace and medical sector, among others.

Keywords: *industrial robots, parallel-link, delta robot, light weight robot, medical robots, aerospace manufacturing.*

Kivonat: *A robotok fejlődése az elmúlt években főleg az előző időszak alapjaira épült, a maga erősségeivel, de figyelembe vette az új alkalmazói igényeket is. A lehetséges tényezők közül az alábbiakat vizsgáljuk:*
- *Az ipari robotok helyzete a maguk termék-életciklusában;*
- *A fejlődés motorját képező innovációk;*
- *A robottechnikában szükséges flexibilitás, és modularitás;*
- *Robotcella adaptációk nagy munkaigényű terekben.*

A jelen cikk bemutatja a jelenlegi helyzet, és víziót ad az új ipari robotok fejlesztői, és gyártói számára. Az ipari robotok olyan új területeken is jól használhatóak, mint a repülőipar, egészségipar, és a gazdaság egyéb fontos területei.

Kulcsszavak: *ipari robotok, párhuzamos kapcsolat, delta robot, könnyű robot, orvosi robotok, repülőipar.*

1. RELATED WORKS

Industrial robots are applied in many industries and sectors, always in a predetermined and controlled environment. The challenges for using robots close to humans are explored by Kemp [1]. Szabolcsi and Mies [2] give a short brief upon history and future of modern robotics, while Struijk in [3] researched the actual position of industrial robots in the Product Life Cycle.

To understand the future of robotics as a category, the Product Life Cycle modeling concept by classical marketers like Buzzel [2] can be applied. Journalist Andy Spilling in [5] reflects on the innovation evolution from normal phones to smart phones. Struijk categorized robots in [6], and [10] to understand the main types of industrial robots. While statistical data from IFR [7] show the rise of

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industrial robots like delta and articulated worldwide. Hirzinger et al. in [8] studied the behavior of robots with sensory feedback towards the interaction and collisions with humans.

A web survey in [9] shows us a sense of the fear that man has for intelligent machines or robots. Miller in [11] studied the dynamics of delta robots. Estey [12] gave an overview of the new standards in robotical surgery. Light weight Robots in general and MIRO in specific were researched by Hagn in [13]. The extension of automation in aerospace industry by Airbus can be found in [14].

Robotics is also deeply penetrated in air applications. There are many segments to be discovered and investigated. In [17], in [21] and [22] Szabolcsi dealt with special UAV applications both for military and non-military purposes. Basic problem of the mathematical modeling of the human operator/pilot is outlined in [15]. The environment in which air robots act is described in [16]. Identification of the UAV flight dynamics model is presented article [18]. Flight path preliminary design is shown in [19] and [20] to provide quasi-optimal behavior of the UAV. In [23] Pokorádi summarizes mathematical theoretical backgrounds for analysis of dynamical systems.

When optimizing robot trajectories it can be shown [24], [27] that by choosing constant kinetic energy motion the trajectory will be much smoother and the motion will use less energy than with other motion (such as time optimal trajectory further discussed in [28]). By using constant kinetic energy motion the operation cost of the robot may be reduced [24].

Difficulties occur when handling non conventional materials with robots (such as soft compressible polyurethanes foam parts). The main problem is that the part changes its shape when handled with an impactive gripper. A simple solution using ingressive (needle) gripper for handling these kind of materials was introduced in [25], and a method for designing such grasping method was given in [26], [27].

2. INTRODUCTION

This paper will focus on the evolution of industrial robots in society. Automation started in the earliest human societies with automata, tools to assist humans in their tedious and heavy tasks. In the past decades, automation and robotics have taken an enormous leap forward in their use and applications. The last decade industrial robots are being used in all industries. New sectors are opening up for robots like aerospace and the medical sector.

The experience gained from the past decades of industrial automation is transforming the industry, putting new challenges on robot design and the way of production. Can a complete new design of industrial robots be expected? Probably, not. There is still a massive growth projected for the coming decades for today’s robots. On the other hand technology is marching forward, and so is the field of robotics. The upcoming trends in innovative robotics like Light Weight Robots, 6 axis delta robots and 7-axes articulated robots will be reviewed. The author will determine in what way robots and their use will be used in the future based on current market information and trends.

3. NEW CHALLENGES IN ROBOT DESIGN AND PRODUCTION

The main question that arises is what challenges do we encounter in today’s industrial robotics field? As technology is progressing at exponential rates, so are the possibilities and applications of industrial robots. Kemp et al argue in [1] that industrial robots are more successful than mobile and/or service robots because they work in a controlled environment. Without vision systems and sensory interfaces, robots have really no perception of their environment, reducing them to programmable machines but with poor added value. So a controlled environment is a prerequisite.

By giving robots perceptual systems and tools they can advance in working under un-certain and un-determined environments. Integrated vision systems are today already common place. The added use of force sensing is moving robotics in general, and industrial robotics in specific in newer areas. Industrial robots indeed have been around for decades [2]. Ever since their first introduction in the last century, their growth has been unstoppable. In [3] Struijk argues that industrial robots have entered the Maturity Stage of the Product Life Cycle (PLC). If we follow the logic of the theory behind the PLC we discover that the Maturity Stage can be as long as 5 to 30 years, a period of few changes on the developed design.

In the Maturity Stage manufacturers switch to streamlined production so as to achieve the needed economies of scale. The product does not undergo many more changes. The market for products in this Maturity Stage is characterized by price pressures due to still high number of suppliers, a steady demand and high acceptance of the product. All these characteristics are valid when taking a closer look at the industrial robot. Through the introduction of complete new solutions, (like how the floppy disks were replaced by USB memory sticks) the current technology can be challenged. But in industrial robot-land no challenger is on the horizon so far.

The Maturity Stage is followed by a sharp decline in demand and basically death of the product, see Buzzel [4]. Robots will form no exception, and despite the fact that Decline Phase is still far off, there are challenges that are putting pressure on the conventional design. The challenges do not come from new products, but can be seen as typical extensions on the main curve of the PLC. They are made through innovations on the basic developed design of industrial robots like articulated and parallel link robots.

These extensions themselves can turn into a new Growth Stage, thus extending the life cycle as a total, see figure 1. A good example is the innovation from the conventional mobile telephone into a smart phone [5]. The mobile phone industry has entered a complete new growth stint. With no new breakthrough technology emerging it is exactly here at this point in the PLC where this paper will focus; the new challenges on robot design. Areas that are being explored and have all the possibilities to re-lift the market to an even higher level.

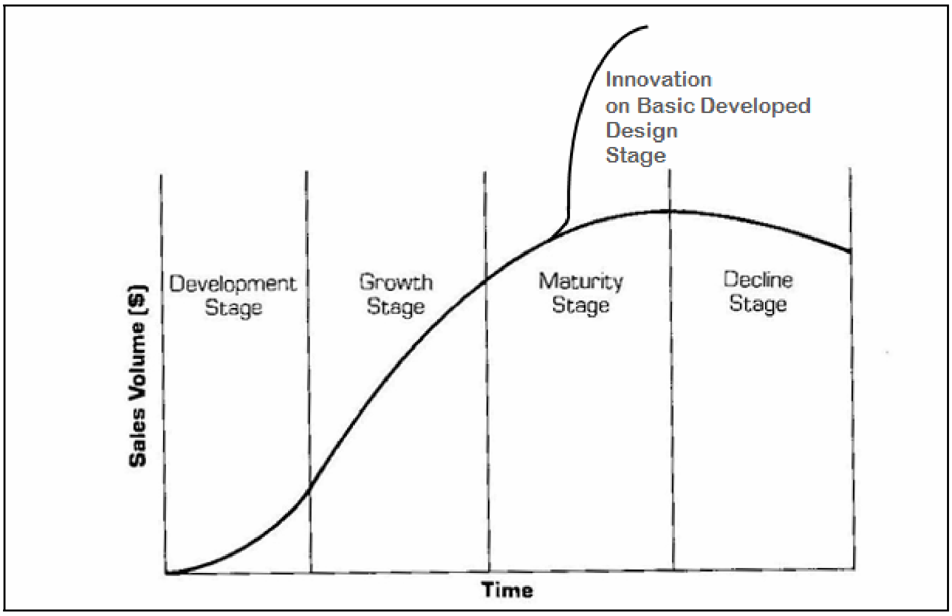

Figure 1. Extended Product life Cycle.

What kind of criteria do we have to take into account to establish whether a new product on the market is a new technology or an innovation based on the basic developed design? For this research three criteria are used to establish the position on the product life cycle.

I. The technological improvement has to be on the existing design, not the introduction of a new technology

II. The market introduction goes via existing channels, and focuses on the same customer target group

III. Innovation must be recognized as such, it should not be a mere product enhancement.

When it comes to industrial robots and design, they can be divided into 4 main categories: Cartesian Robots, Scara Robots, Articulated Robots and Delta Robots (also known as parallel link robots) [6]. Researching the evolution over the last 5 years, there are in total 3 new and innovative solutions based on the conventional and proven robotics that comply with the above mentioned criteria.

These are the following innovations:

- Light Weight Robots
- 7-axis Articulated Robots
- 6-axis Delta Robots

Each of these three innovations is positioning industrial robots on a new extended product life cycle path. Certainly the limitations in the conventional design have pushed for these developments. Accessibility and flexibility have always been the center of modern industrial robotics. Modular design is in direct conflict with reaching economies of scale through mass production while mobility is in direct conflict with a conditioned environment, a pre-requisite for today's industrial robot. But with the realized benefits of deeper integration of robotics in our factories, the need to position them closer to humans is evident.

This requires a fresh look at the conventional design. All three of these innovations can be found in the market today. They are in their initial phase of the extended growth path and acceptance. One group worth mentioning is that of Service Robots (mobile robotics). These robots do not match the stated criteria as they offer a new feature that current industrial robots do not possess, that of autonomous mobility.

Also they focus on a different segment, namely domestic use first and foremost. Hence it is classified as a new product. Service Robots are still in their Development Stage of the PLC. The Service Robots will therefore not be considered at this point. Many manufacturers and universities built prototypes, some with big future potential.

3.1 Light Weight Robots

Traditional articulated 4 to 6 axis industrial robots base their success on working in an environment which is adapted to their use. They possess a large Return on Investment ROI, often realised within one year. This ROI is realized through the design of robotic cells specially for their purpose, like handling cells, arc welding cells etc.

The repetitiveness achieved in these created surroundings, combined with precision and high quality output form the basis of their success. Cost efficiency of industrial robots is reached through economies of scale; produced en-mass from steel castings they have generally a large weight, albeit a poor weight to payload ratio, they have a high stiffness and can carry large payloads.

With a total stock of operational robots world wide of about 1.300.000 robots in 2009 [7] the experiences gained by end users in industry are huge, pushing the needs further. Once an end user of robotics has tasted the gains of using flexible automation with robots, they have a need for more. But not always can you create an environment dedicated for a robot.

The origins are often the rapid changes of the environment, or the very short series of products to be processed, or the closeness of humans which makes robot automation impossible due to the safety needed. Traditional robots clearly do not fit this picture. So Light Weight Robots came into vision beginning of the new century. These are robots, based on traditional articulated robots but especially designed for use and placement in unknown environments, possibly mobile.

Typical two characteristics of traditional industrial robots, as described above do not possess. Also Light Weight Robots are designed to interact with humans. Mobility and flexibility require a light-weight design with a high load to weight ratio. Optimally a 1:1 ratio, combined with high speed. To fulfill the need for flexibility the build typically should be modular, with integrated mechanical and electronic design. These light weight robots also have control capabilities and sensory skills for complete interaction.

Figure 2. Light Weight Robot by Kuka.

The shown KUKA light-weight robot has seven degrees of freedom, a load capacity of 14kg and weight of 14 kg. The load to weight ratio therefore is an optimal 1:1. Further this robot has joint torque sensors in each joint, which are connected through carbon fiber structures, and a redundant position measurement. Cabling is all within the arm, using fiber optic bus systems. In this way it can sense human workers and react accordingly in a safe manner. In [8] Hirzinger et al show that the DLR robot, the prototype on which the Kuka unit is based, is able to detect and distinguish unexpected collisions from an intended cooperation, in which a human stretching out his arm, tries to catch the robot.

According to their research this provides a “subjective safe feeling”, it is safe because the user interprets the robot behavior as safe. The study showed that the robot inflicted no harm to the operator at any of the considered velocities and it was always possible to detect the collision and let the robot switch to one of the investigated reaction strategies. These Light Weight Robots are intended to be used close to humans. Therefore, apart from compliance to international safety standards, the fact that the robot stops at even the lightest touch compensates the intrinsic mistrust, even fear from humans towards intelligent machines [9]. Later in this paper we will focus on the medical applications for Light Weight Robots.

3.2 Articulated robots with 7-axis or more

If innovations on the basic developed design extend the life of a product, and even can turn them into a new growth phase, then there is a second group of innovations that qualifies and is worthwhile investigating; the articulated robots with 7 axis.

Traditionally articulated robots have 6 degrees of freedom, which allow them to reach any point in space from whatever angle, depending on the position of the point in its work envelop. Although 6 degrees of freedom suffice in most applications, in some specific cases the robot needs to be positioned in a calculated position in order to reach the desired output. By adding a seventh axis, or “elbow”, access to difficult areas are improved substantially. The robot does not need to be in a specific calculated position. This 7-axis design copies human flexibility into industrial articulated robots.

The advantages are obvious, as this robot design can save valuable floor space in or near machines. The addition of the 7^{th} axis dramatically increases the freedom of movement around the elbow. Conventional 6-axis articulated robots can just not access all positions unless they are positioned in a specific way. Example shown below (see Fif.3.) is the robot working “around a corner”, in a very limited space loading and unloading a CNC machine tool from a warehouse.

Figure 3. A 7-axis articulated robot by Motoman loading a machine center

Another gained benefit of the 7 axis industrial robot is that with this design a programmer can avoid unwanted singularity points by giving multiple posture solutions for the same tool center point. The tool attached to a 7 axis robot, i.e. a welding torch, can remain on the target at the same angle while the robot repositions. These 7-axis robots have been introduced since only 5 years and steadily find their way into the market.

The increased flexibility comes at a price, as one has to add another motor, drive, gear, cabling and the design of the arm has to be reconsidered as stiffness comes into play. Main markets for these robots are machine load and unload and arc welding. It is expected that within a 3 year time frame all major robot manufacturers will carry 7 axis articulated robots in their portfolio. Today these machines are carried by some of the leading Japanese robot manufacturers.

3.3 Delta robots with 6-axis

Delta robots, also known as Parallel Link Robots are the last category of modern day robotics, introduced in the late eighties. This kinematic solution provides a conical or cylindrical work envelope and is most frequently applied to applications where the product again remains in the same plane from pick to place, XYZ [10][11].

Delta robots, given their structure, are used for high-speed handling of lightweight products. Since its introduction in 1999 into the industrial robotics market by Swiss-Swedish manufacturer ABB, the design has not changed. These robots can be found in various markets like food industry, the electronics sector as well as pharmaceutical industry, for high speed Pick & Place of various products and components.

Innovation on the basic design came from an unexpected angle; the marriage of xyz plane using parallel-link technology and the 6 degrees of freedom as used by articulated robots. It was FANUC Corp, the Japanese world leader in robotics that launched in 2009 worlds first delta robot with 6-axis and hollow wrist.

Figure 4. FANUC 6-axis delta robot.

This new innovative design of a delta robot combines the best of both worlds. First, through its traditional parallel-link design, it can achieve high speeds for pick & place applications in a large work envelop. Second, by adding drives for axis J5 and J6 the standard delta robot for x, y and z is turned into a six axis robot.

The created hollow wrist can orientate and position (pitch and yaw) products in full special capacity along x,y,z,p,q,r. Clearly advantageous when a product which is picked up by the robot needs to be positioned in a reoriented manner or when it has to be inserted in i.e. a blister while using a wrist movement for proper insertion.

The design by FANUC achieves also a high stiffness of the J4 joint by adding the motors for the wrist in the arms. The drive mechanisms towards the wrist having constant length, avoiding the maintenance intensive telescopic arms, and hence improves the desired stiffness. Thanks to this design this robot can handle payloads of up to 5 kg, where normal delta robots have difficulties of handling more than 2kg.

4. NEW APPLICATIONS

Industrial robots work mostly in predetermined conditions and closed environments. This is probably just fine to cover for the many industrial needs based on large series and repetitiveness. More and more we find industrial robots in industries far away from the original automotive industry. Slaughter houses use industrial robots equipped with vision systems to cut open cows and pigs. Robots positioned on 4x4 trucks are used to position solar panel in deserts and other remote areas. Even the flower industry has embraced robots for planting seeds at high speed.

All these applications are based on existing technology and available technology. However, take for example the process of building a modern airplane. This is still mostly done manual. In case automation is used it consists of dedicated equipment, with low flexibility and high investment costs. The series are small, the complexity is high and there is the need for quality and precision. i.e. it is not so easy task for an industrial robot. Same goes for the many medical processes.

4.1 Light Weight Medical Robots

Automation by using robots in the medical sector is growing fast. In the last decades robotics and remote robotics are being introduced into more and more in our medical applications. With its high repeatability and arm rigidity the field of surgery has a large potential. It can provide medics with an additional option in how to tackle complicated medical issues. The main benefits can be found in precision, smaller incisions, which means less pain and side effects [12]. Healing is faster, so costly hospital time is reduced and throughput increased. The Light Weight Robot surgical robot MIRO from DLR is a good example of these new applications for robotics.

Figure 5.The MIRO surgeon robot.

Hagn in [13] shows that the developed surgeon robot MIRO by DLR with its integrated torque sensors and light weight design and extended versatility can be used in the operating theatre for a limited range of surgical applications. Although robots are inherently flexible and versatile, it does not mean that a robot, like MIRO, can perform all required medical surgery tasks. Modularity is part of the solution, as the robot becomes scalable towards the required application, and tuned by its parameter settings.

In addition, versatility can be achieved by adding dedicated instruments to the robot's universal end effector, and wrist design and adapting its many internal control sensors.

4.2 Aerospace and Robotics

Another field where new applications of industrial robots are being applied is that of aircraft manufacturing. As the whole assembly and paint process is still done mostly manual, large cost reductions could be achieved if standard industrial robots could be applied. Most parts and components in the aerospace industry are complex and large of size, the production volumes are typically low. Also aerospace industry typically requires tighter tolerances, and uses lighter, stronger materials than normal industries like car industry. Even combined composite materials are used.

Today articulated robots are for more affordable than dedicated machinery for the same purpose, while their setup and programming, supported with offline 3d software is relatively easy. Due to the large sizes, mobility is a must. As a result large gantry systems are used in most cases, equipped with dedicated machines and tools. These are quite inflexible machines that need to be replaced with each aircraft model. So when the aim is to use flexible automation either conventional 6-axis articulated robots come into play, positioned on gantry's, or Light Weight modular robots. The latter being easily mounted on movable platforms and they can work closely to the factory worker.

Typical applications in aerospace industry: Drilling, Riveting, Grinding, Polishing, Sandblasting, Painting, Coating. All these applications can be done with existing robots. But a shift in part design needs to take place, as happened in the automotive industry, where parts are designed in such a way that its manufacturing can be automated. The aerospace industry definitely lags behind here. Drilling is a high-volume operation in aerospace, hundreds of thousands of precisely located, straight holes per aircraft. Airbus drills 50 million holes per year, of which half are done manually [14]. The aerospace requirements in terms of payload capacity, rigidity and accuracy could not be handled with standard industrial robots. However industrial robots enhanced with higher calibration and using vision systems and high level off-line programming do reach the stringent aerospace standards.

5. CONCLUSIONS

Industrial robots keep finding their ways in new areas. Since their introduction they have been a success. Now new innovations on the basic concept for articulated and delta robots allow new growth. Light weight modular robots will find their entry in industry, medical applications and aerospace manufacturing.

By adding more degrees of freedom, a 7th axis in the case of articulated robots and the addition of a wrist to delta robots, a new range of applications is being fulfilled by using these innovations on the conventional robots. Design follows function. In general, all robots should contribute to a more sustainable society.

More and more robots will become more capable of replacing humans, and by adding vision and force sensing they get eyes and touch. Still human workers will always be needed, whether in industry, medical or aerospace manufacture. Their involvement will be different though.

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SOURCES OF FIGURES USED ABOVE

Figure 1. **Theoretical Product life Cycle** Derek F. Hall Strategic Market Planning, P.60, ISBN 0-13-851049-0 01

Figure 2**.** Picture of **Light Weight Robot** (LWR) by KUKA Roboter GmbH

Figure 3. Picture of **MOTOMAN 7-axis robot** (IA20), source: http://www.motoman.si/uploads/tx_catalogcasestudy/The_Snake_sneaks_into_production_08.pdf

Figure 4. Picture of **FANUC Delta robot** (M-3iA/6A) by FANUC Corp. Ltd.

Figure 5. DLR surgeon robot, MIRO, by German Aerospace Center, Institute of Robotics and Mechatronics, Robotic Systems. Source: http://www.dlr.de/rm/en/Portaldata/52/Resources/images/bildgalerie/miro_02.jpg.