Innovative Technologies and Materials in Robotics

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***Abstract**: The purpose of this report is to examine the challenges of today's robotics, new materials and technologies that can be used to find new constructive solutions, improve grip in order to increase static robot stability and development of details with complex shape. A com-parison of traditional manufacturing methods, 3D and 4D printing technologies has been made in terms of cost, speed, design and quality.*
***Keywords:** 3D and 4D printing technologies and materials.*

1. INTRODUCTION

Robotics is in the top 10 of the EU's priority science areas in the agenda 2020 and is leading one for all economically developed countries (USA, Japan, China, Korea, Rus-sia, etc.). In the Renewed Strategy for the Development of Scientific Research in Bul-garia for the period 2016-2019 mechatronics is at the forefront of the scientific priorities.

The definition of Robotics as a priority scientific field is related to the wide range of applications (industry, medicine, life and social activities, military and police activities, ground and space research, etc.) and the qualitative changes they make. Robotics is field of science that integrates mechanical engineering, computer sciences and electri-cal as well as new methods of computation and artificial intelligence. The modern robots have three core components: a body, a brain and electricity supply. So the focus of re-searchers in the field of robotics nowadays is on development of novel smart materials and using new technologies in constructions and remarkable progress has been made in many aspects – in bioinspired designs, additive manufacturing (known also as 3D printing) smart materials, etc. The goal of this paper is to present the results from con-ducted research of new materials and the specific features of using 3D printers to im-plement nodes and robot models according to work package one the project, financed by Bulgarian NSF.

2. CHALLANGES IN ROBOTICS

The major unsolved challenges in robotics could be formulated in the following chal-lenge groups [1]:

- **New materials and fabrication schemes –** artificial muscles, compliant materi-als for soft robots, development of multiscalar materials able to adapt and heal over time, emerging advanced manufacturing and assembly strategies thus providing 4D robots that achieve the complexity found in natural systems; devel-opment of materials by integrating molecular machines, or other force-generating molecules or biological motor proteins, into hierarchical materials; combination of techniques from micro-/nanoscale fabrication, mesoscale methods as layering and lamination , and the myriad macroscale multi-axis subtractive methods; new kinematic (mobile) compounds by analogy of biologic that allow concentration

- more than one movement between two units of higher accuracy and load carry-ing capacity;
- **Bioinspired robots** - creation and development of new types of propulsion and data analysis systems based on bionic principles (fish fins, dragonfly eyes, but-terfly wings, etc.); Imitation of the principles of movement of living organisms (walking machines) and the principles of echolocation of bats, dolphins etc.;
- **New power sources, battery technologies and energy-harvesting schemes -** development of high–energy density batteries (based on solid electrolytes and radioisotope power systems) to support robots working in challenging conditions and extreme environments; establishment of mechanisms for harvesting me-chanical energy, including electromagnetic and electrostatic generators, as well as piezoelectric or triboelectric nanogenerators, etc.;
- **Swarm robotics** – development of methods for control of group of robots, Preci-sion manipulation of large-sized and massive objects; Development of algorithms and protocols for information exchange, taking into account restrictions on the capacity of communication channels, transmitters and energy costs; develop-ment of algorithms for tasks distribution between agents taking into account their current state. development of robust and uninterrupted communication systems between robots and operators (for multi-agent systems) under conditions of un-certainty and the presence of unpredictable interference;
- **Navigation and exploration in unstructured environments –** development of methods of adaptive control of the movement of robots and multi-agent robotic systems under conditions of uncertainty and significant external conditions; de-velopment of real-time databases for knowledge representation; development of artificial intelligent methods for analysis, control and prediction the functioning of robotic systems;
- **Application of artificial intelligence(AI) methods in robotics** – ability of AI to perform deep moral and social reasoning about real-world problems; creation of robots with AI, which are able to detect their own subcomponents and state, model their operations, and modify those models if their structure changes;
- **Brain-computer interfaces** (BCIs) –allow the robot to perform remote tasks; use of brain activity to control a computer or external device;
- **Medical robotics -** development of interfaces between a robotic device and a bi-ological organism; creation of molecular biorobots; development of surgical sys-tems combined with visualization methods to improve diagnosisis and positioning; improvement of telemedicine technologies; development of an intelligent adap-tive learning system for robots for manipulations in various areas of surgery; de-velopment of algorithms for recognition specific scenarios of human behavior from visual information for monitoring the condition of workers, chronic patients and elderly people;
- **Social interaction** that understands human social dynamics and moral norms development of algorithms for recognition and synthesis of natural speech; syn-thesis of algorithms for recognizing specific scenarios of human behavior in order to prevent aggression in public places; development of methods for rapid train-ing of robots (simulators);

- **Ethics and security** for responsible innovation in robotics.

3. PRINTING TECHNOLOGIES

The additive manufacturing (3D printing) is a method that involves joining materials to make objects from 3D model data, usually layer upon layer at the time. A large num-ber of additive manufacturing processes are now widely used, because it is a great so-lution to work on robots design, to create new functionalities and to develop mass cus-tomization; they differ in the way layers are deposited to create parts, in the operating principle and in the materials that can be used [2, 3].

Stereolithography (SLA) - a laser-based technology that uses a UV-sensitive liquid resin and a UV laser beam, which scans the surface of the resin and selectively hard-ens the material, building the 3D part from the bottom to the top. The produced parts are highly accurate with smooth surface finishes and are commonly used for highly de-tailed objects [4].

Materials. Poly1500 is suited for rigid, functional prototypes in a large range of ap-plications such as automotive components, electronic housings, snap-fit assemblies and medical products; Tusk2700 are suitable for strong, water-resistant prototypes with ABS- and PBT-like specifications, Taurus - a charcoal black material, suitable for func-tional prototypes and form-, fit- and function-testing; Tusk SolidGrey3000 is the world's first SLA material that combines a high degree of stiffness with high impact resistance and is suitable for automotive body parts, machine covers, functional prototypes, dura-ble concept models and robust scale models; NeXt is an extremely durable resin for very accurate parts; ProtoGen White is suitable for general purpose applications with ABS-like specifications; PerFORM produces strong, stiff parts with high thermal re-sistance.

Digital Light Processing (DLP) is a similar process to SLA and a projector also is used to cure photopolymers with the difference that instead of a UV laser a more con-ventional light source is used, such as an arc lamp with a liquid crystal display panel. Objects are created similarly to SLA with the object being either pulled out of the resin, which creates space for the uncured resin at the bottom of the container thus forming the next layer of the object, or down into the tank with the next layer being cured at the top. DLP produces highly accurate parts with excellent resolution, but also include the same requirements for support structures and post-curing. DLP technology could be used also for Silver and Brass 3D printing [5].

Continuous Liquid Interface Production (CLIP) - a relatively new 3D technology, which uses several thermoplastic engineering technologies. The CLIP chemical process works by balancing oxygen and light to discriminately cure photo liquid resin. CLIP works by projecting a continuous sequence of UV images, generated by a digital light projector, through an oxygen-permeable, UV-transparent window below a liquid resin bath. The dead zone created above the window maintains a liquid interface below the part. Above the dead zone, the curing part is drawn out of the resin bath. Since a con-tinuous sequence of UV images is reflected on the surface as the object being drawn, the technology makes it easy to continuously grow 3D objects without interruption. Some of the most preferred materials include glass filled nylon, which is temperature resistance and the highly resilient injection molded polyurethane elastomer. [6].

Selective Laser Sintering (SLS) - a powder-based layer-additive manufacturing process when small plastic, glass or ceramics particles are fused together in predeter-mined sizes and shapes of layers using high power laser, either in continuous or pulse mode. The geometry of the scanned layers corresponds to the various cross sections of the computer-aided design (CAD) models or (STL) files of the object [4].

Materials - The most common materials are: wax, paraffin, polymer-metal powders, or various types of steel alloys, polymers, nylon and carbonates. PA 12 (Polyamide) al-lows the production of fully functional prototypes or end-use parts with high mechanical and thermal resistance; Alumide (Polyamide Aluminum-Filled), TPU 92A-1 is the only 3D printing material that combines the qualities of durable elasticity, high tear and abra-sion resistance, high resistance to dynamic loading, snappy response and a good ther-mal resistance (-20°C to 80°C).

Direct Metal Laser Sintering (DMLS) - comes to direct 3D printing of metals and is one of the world's most advanced manufacturing technologies. DMLS uses a laser as a power source in order to sinter metal powder by aiming a laser and tracing a cross sec-tion of the object layer by layer. The method is similar to the selective laser sintering process [7].

Laminated object manufacturing (LOM) - was developed by the California-based Helisys Inc. (now Cubic Technologies). During the LOM process, layers of plastic or pa-per (rare metal) are fused (laminated) together using heat and pressure, and then cut into the desired shape with a computer-controlled laser or blade. The LOM is not the most popular method of 3D printing used today, but it is the fastest and inexpensive way to 3D print objects in several kinds of materials [8].

Fused deposition modelling (FDM) - the most common 3d printing method. FDM printers use a thermoplastic filament, which is melted to semi-liquid state and then ex-truded, layer by layer, to create a 3D object. FDM printers use two kinds of materials: a modeling material, which constitutes the finished object, and a support material that acts as a scaffolding to support the object during printing process. In a typical FDM system, the extrusion nozzle moves over the build platform horizontally and vertically, "drawing" a cross section of an object onto the platform. This thin layer of plastic cools and hard-ens, and immediately binding to the layer beneath it. Once a layer is completed, the base is lowered — usually by about one-sixteenth of an inch — to make room for the next layer of plastic [9].

Materials. FDM printers are compatible with a wide variety of thermoplastic poly-mers like PLA and ABS, but also Polycarbonates such as PET, PS, ASA, PVA, Nylon, and even composite filaments based on metal, stone, wood, etc. These composites of-ten offer interesting mechanical properties such as being conductive, being bio-compatible, or being heat resistant.

Electron Beam Melting (EBM) – process, in which metal powder or filament is completely melted by a concentrated beam of electrons. Production in a vacuum cham-ber ensures that oxidation will not compromise highly reactive materials like titanium. Vacuum production is also required so electrons don't collide with gas molecules.

Materials. the materials used must be conductive. Without this, no interaction can occur between the electron beam and the powder. The manufacturing of polymer or ceramic parts is therefore technically impossible with an electron beam. Titanium's lightweight, superior strength and corrosion resistance have long attracted designers and engineers in the aerospace and defense industries [10].

Selective laser melting (SLM) - The technique can be used for the additive manu-facturing of stainless steel, tool steel, titanium, cobalt chrome and aluminum parts. Re-searchers hope that the SLM will one day be used to manufacture parts made of other metals, but there are difficulties that still need to be resolved. Many other metals do not have the correct flow characteristics that are needed to make them suitable for SLM.

Materials. The materials used include: Stainless steel; Tool steel; Aluminum alloys (Al); Titanium and titanium alloys (Ti); Cobalt-chromium alloys (CoCr); Bronze alloys; Precious metal alloys; Nickel-base alloys [11].

Tab. 1: Comparison of different production technologies

Traditional manufacturing	**3D printing technology**	**4D printing technology**
• Expensive manufacturing • Higher costs of shipping and other logistic activities of the products	• Saves up to 70% of prototyping costs • saves energy by 40-65%	• The production costs are reduded significantly because no cost and time for debugging and checking the "printed" wires, sensors, etc. • No shipping and other logistic activities
• Less innovative design • It is difficult to produce objects of complex shape	• Allows for easy and inexpensive innovation in design • No matter what is the shape of the printed products • Selective material deposition significantly reduces the mass of the product by printing the frame structures. The freedom of designing the shape extends to the inner structure of the material	• Absolute freedom of design. The ability of the product to adapt its shape to surrounding conditions, both on its own and on command
• Need a lot of time to build the final product	• Less time consumption due to compressed design cycle	• Less time consumption
• A great amount of waste of materials • Subtractive process will compromise precision	• Small amount of waste • High precision (layer by layer production)	• A situation similar to 3D printing
• The production of details is carried out with significant participation of a Human-operator	• The production of 3D objects is carried out in accordance with a standardized program (under control of a computer), so the participation of a human is minimized	• • The degree of simplification of production increases; the constituent elements are simple and they are printed quickly and activated in some way. The elements could be adapted to the conditions during production and transportation to the end users
• Effective for huge number of similar products • It is difficult to reconfigure the production lines when the release of another product is needed.	• Allow to produce a huge range of products, • Production lines could be reconfigured easily and quickly if release of another product is needed.	• A situation similar to 3D printing, since all components could be printed
• Distributing of final products	• Distributing not products, but their projects in files, so they can be transmitted to any place using the Internet and can be printed anywhere in the world	• It is enough to purchase a set of voxels, download the program from the cloud, and then independently produce the desired thing

Nowadays the development of programmable matter goes in two directions:

1. Creation of products using 4D-printing methods - printing blanks using 3D-printers, and then they are self-transformed under the influence of a predetermined fac-tor, for example, moisture, heat, pressure, current, ultraviolet light etc.
2. Production of voxels (or three-dimensional pixels) on 3D printers. These voxels can be connected and disconnected in order to form larger programmable structures. Voxels can be digital and physical. Digital voxels are used for the virtual representation of the 3D model. Physical voxels are elementary volumes of homogeneous materials or multicomponent mixtures, nanomaterials, integrated circuits, biological materials and micro-robots, etc.

The comparison of traditions manufacturing methods, 3D and 4D printing technolo-gies as regards to costs, speed, design and quality is given in table 1.

4. CONCLUSIONS

The 3D technologies allow creation of a new type of directly assembled kinematic compounds. A new type of robot construction will develop and the speed is improved significantly; allow realization of details with complex shape, including internal cavities ; creation of robot models inspired by nature; creating a new types of mechanisms; gives ability to obtain details of heterogeneous materials and new qualities. Based on the re-search of the technologies and the materials for the 4D and 3D printing, suitable design solutions will be chosen and the possibilities of creating units of extremely complex form to be implemented in the so-called robot models developed by the team.

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5. REFERENCES

[1] Yang et al., “The grand challenges of Science Robotics,” Science Robotics, 23, 2018.

[2] Bikas, H., P. Stavropoulos, G. Chryssolouris, “Additive manufacturing methods and modelling approaches: a critical review,” International Journal of Advanced Manufacturing Technology, 83, p. 389–405 , 2016.

[3] Gladman, A. S. et all“ Biomimetic 4D printing”, Nat. Mater., 15, p. 413–418, 2016.

[4] Bakshi, K.R., A. V. Mulay, “A Review on Selective Laser Sintering: A Rapid Prototyping,” IOSR Journal of Mechanical & Civil Engineering , pp. 53-57, 2016.

[5] Aznarte E. et al., “Digital light processing (dlp): anisotropic tensile,” %1 Proceedings of the 28th Annual International Solid Freeform Fabrication Symposium, 2017.

[6] Balli, J.et al., “Continuous Liquid Interface Production of 3D Objects: An Unconventional Technology and its Challenges and Opportunities, ASME 2017 International Mechanical Engineering Congress and Exposition, Tampa, Florida, USA, November 3–9, 2017.

[7] Duda, T., L. V. Raghavan, "3D Metal Printing Technology," International Federation of Automatic Control IFAC-PapersOnLine 249-29, p. 103–110, 2016.
[8] Palermo E., "Fused Deposition Modeling: Most Common 3D Printing Method," September 2013. https://www.livescience.com/40310-laminated-object-manufacturing.html.
[9] Varotsis A., "Design Rules for 3D Printing," http://www.core77.com/posts/74401/
[10] Gong, X. T. Anderson, K. Chou, "Review on powder-based electron beam additive manufacturing technology," ASME/ISCIE 2012 International Symposium on Flexible Automation, American Society of Mechanical Engineers, 2012.
[11] Ya, C.Y. et al "Review of selective laser melting: materials and applications," Appl. Phys. Rev., 2, 2015.