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MEDICAL AND MILITARY APPLICATIONS OF 3D PRINTING

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Abstract:

3D printing, 3D scanning and reverse engineering may constitute a significant breakthrough in research all over the world, especially within medical and military technologies. Particularly 3D printing seems to be a promising method to produce 3D objects manufactured layer-by-layer. The broader use of the above technologies may allow customization of various products and lower costs of design and production. At the same time progress in 3D printing technologies needs to be monitored and analyzed in order to deal with possible future threats. This article aims at investigating the extent to which the military and biomedical applications of 3D scanners and 3D printers are exploited, including in the framework of the authors' own concepts, studies and observations.

Keywords:
3D printing, 3D scanning, reverse engineering, military applications, biomedical applications

INTRODUCTION

3D printing and 3D scanning technologies constitute relatively new concepts that are supposed to cause economic and social revolution due to significant improvement or replacement of the current models of production, distribution and consumption of goods and services, primarily in industry, science, art and architecture, but also education, medicine or defense. Their principal application areas cover:

- 3D scanning – enabling contactless measurement and record of characteristics of physical objects in the form of digital files (an object's documentation);
- 3D printing – allowing for manufacturing objects (including those previously not existing physically, but only in the computer memory) from digital files, the most frequently with the method of layering used (depending on the technology, for example MEM (melted and extruded modeling), / FDM (fused deposition modeling) /, LOM (laminated object manufacturing), etc.);
- reverse engineering – allowing the creation of 3D documentation of physical objects of various sizes, and the subsequent processing of the said data into 3D printing to duplicate, test or upgrade an object.

The thought and deliberate combination of the above technologies has the following advantages:

- ease-of-use (based on specialized software: user-friendly processing of the results, the ability to save data in popular file formats and share them quickly with other users);
- printing speed;
- relatively low cost (both of manufacturing (including within the recycling of raw materials) and indirectly by reducing a project team, the lower cost of prototypes, shorter prototyping time and the lack of warehouses and shops - in the case of printing directly at the user's place);
- the possibility of selection of materials (plastics, metals, ceramics, living cells, technologies of simultaneous printing from multiple materials) and technology;
- the possibility of merging different materials;
- the aesthetics of final products;
- the possibility to automate the measurement process (in some applications);
- the improvement of the accuracy of measurement without calibration in each case, even when testing not only shapes, but also texture of objects;
- the compact design of devices, mobility (in some applications);
- non-invasiveness (in some applications, which is of significant importance when measuring living objects or museum exhibits, monuments, etc.);
- the improvement of the confidentiality of trade secrets (by reducing the number of project teams and prototypes to a minimum, as well as storing data in the form of easily encrypted digital files instead of sending prototypes or forms for their production).

This ensures quick creation of objects of complicated shapes and internal structure with precision impossible to achieve by means of other technologies.

Availability of relatively cheap computer sets (low-cost 3D printing) and free software facilitates the dissemination of the said technologies [1-11] and creates a completely new market, resulting from the simultaneous satisfaction of two opposing trends:

- emphasis on low-cost, mass production, accessibility to most customers;
- meeting the clients' need to have exceptional and unique items.

At the same time technologies constitute themselves a source of hazard: a variety of materials and technologies requires careful selection of their applications, and the final product features may also be dependent on the complexity of an object, print resolution and speed. Further research in this area is therefore necessary, especially in the direction of standardization and the avoidance of potential dangers of this group of solutions under discussion.

Limitations of 3D technology also include:

- the accuracy;
- the number of available materials and their parameters;
- legal restrictions concerning e.g. manufacturing weapon elements, protecting copyrights, reproducing works of art, etc.

The aim of the study is to assess the extent to which the military and biomedical applications of 3D scanners and 3D printers are used, including within the authors' own concepts, research and observations. Currently, tests have been conducted by the Mechanics and IT Institute at the Kazimierz Wielki University of Bydgoszcz in cooperation with the Physiotherapy Department, the Ludwik Rydygier Collegium Medicum, the Nicolaus Copernicus University in Toruń, the Rehabilitation Clinic at the 10^{th} Military Research Hospital with Polyclinic in Bydgoszcz and the Neurocognitive Laboratory at the Interdisciplinary Center for Modern Technologies (LNK ICNT) of the Nicolaus Copernicus University in Toruń.

1. BIOMEDICAL APPLICATIONS OF 3D PRINT

The widespread introduction of 3D printing, 3D scanning and reverse engineering to biomedicine can contribute to the reduction of the cost of design, implementation and application of new therapeutic approaches (as well as the optimization of the existing ones), accelerate the development of personalized medicine (patient-tailored therapy) and improve the matching of medical products (tools, orthopedic equipment and medicines) to the needs of therapy / a patient. 'The right therapy for the right patient at the right time' will become more accessible and will translate not only into the increase in therapy effectiveness, shorter hospitalization and transfer of a part of therapy to out-patient or home conditions but also into the better use of already available measures of health care and welfare systems. However, this requires the adaptation and synergistic effects of new 3D technologies as well as these currently used in biomedicine, such as:

- 3D diagnostic imaging: computed tomography (CT), functional magnetic resonance imaging (fMRI) and reconstruction of 2D images to 3D;
- the nextensive use of 3D (neuro) anatomical digital atlases (including the determination of access ways to sources of neurosurgery in surgery);
- localization of signal sources position based on the electroencephalographic (EEG) or magnetoencephalographic (MEG) signals;
- the need for realistic (anatomically and functionally) phantoms and other educational materials, also in the context of dynamically developing medical simulation centers;
- fabrication of artificial tissues and organs;
- technologies deemed to be forward-looking, primarily nano-medical and atto-medical ones [12-15].

This can lead to a qualitative leap in the education of medical professionals, diagnostics, treatment and rehabilitation planning, transplantation of tissues and organs (also artificial ones). For this reason, the key areas of research, including clinical research, relate to:

- printing personalized anatomical models and phantoms for the individual training and team integration in medical simulation centers;
- printing components for scientific research, in the area of testing properties of bones and soft tissues as well;
- rapid (lasting up to several seconds) 3D scanning of a face / head or a whole body, mostly for the purposes of prosthetics or reconstructive surgery, including in children;
- fast (up to a few hours) and relatively inexpensive fitting and printing items of broadly understood assistive technology, including orthopedic and personalized computer accessories for people with disabilities – due to the fact that the chronically ill, the disabled and the elderly constitute the increasingly larger group of patients, but at the same time they are considered to be more and more important target group for trade and industry;
- printing medical devices and their elements [16];
- printing medical products, for example dressings of desired shapes and properties (Cortex) and spectacle frames;
- printing tissues and organs from biological cells [17];
- personalized prosthetics (with new technologies in the area of selection and preparation of implants – from the teeth and jaws to the limb prostheses – including solutions ‘growing’ with children);
- personalized forms of distribution of drugs within the body [18, 19].

Limitations here are properties of materials, and in particular:

- restrictions arising from the long-lasting contact with living tissues;
- the need to meet a number of conflicting requirements, for example in terms of stiffness simultaneously with flexibility, which requires the parallel printing from multiple materials having different mechanical characteristics;
- requirements for resistance to moisture, contact with drugs, etc., as well as anti-allergic properties.

The most interesting solutions include:

- printing with biological cells – which permits dimensional stability and characteristics of a tissue but also – when printing with the use of the patient's stem cells - to minimize transplant rejection [21-23];
- printing parts of the skeletal system, including scaling up to the age and size of a patient [24-29];
- coping with material limitations by using 3D printing and reverse engineering to fabricate forms (individual for each patient) to perform the right products or only selected elements of prostheses [30-35];
- printing elements: seats in wheelchairs for the disabled, adjustable elements of exoskeletons (WREX) and rehabilitation robots individually matched to the patient's state of health and deficits.

The major advantage compared to the solutions currently used is the possibility to process any 3D digital files relatively fast, and hence modify geometric parameters (scaling and adaptation of solutions) as well as choose materials of desired qualities (also print individual elements of a product with the use of various materials, including layering), both in respect of prototypes, forms and templates, as well as final products. With regard to biomedical applications it requires adequate knowledge in the areas of mechanics, mechatronics, materials engineering, as well as biomechanics and physiology. Thus, the interdisciplinary research is necessary, particularly in the area of innovative 3D printing technology, as well as fabricating materials for medical applications, including those replacing traditional dressing materials or metals. Particular progress is expected in the area of rehabilitation engineering, thereby increasing the therapy effectiveness and quality of life of the chronically ill, the disabled and the elderly.

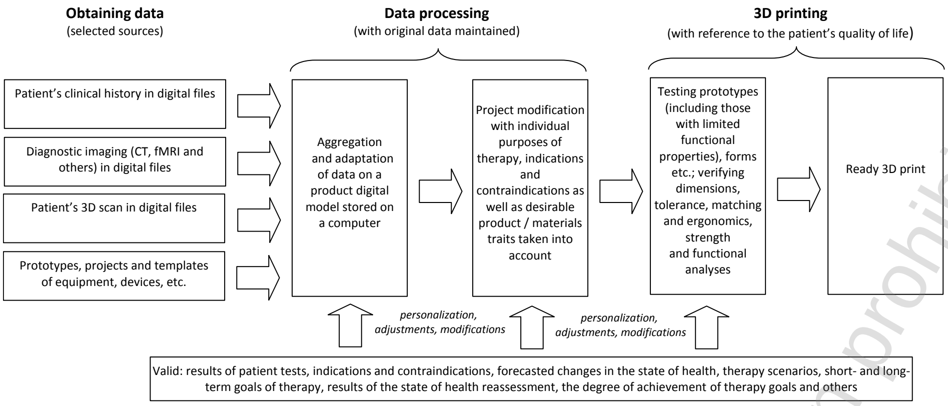

Fig. 1. The model of manufacturing a medical product using 3D printing / variant - own study / - also available partially automated.

Source: Own study

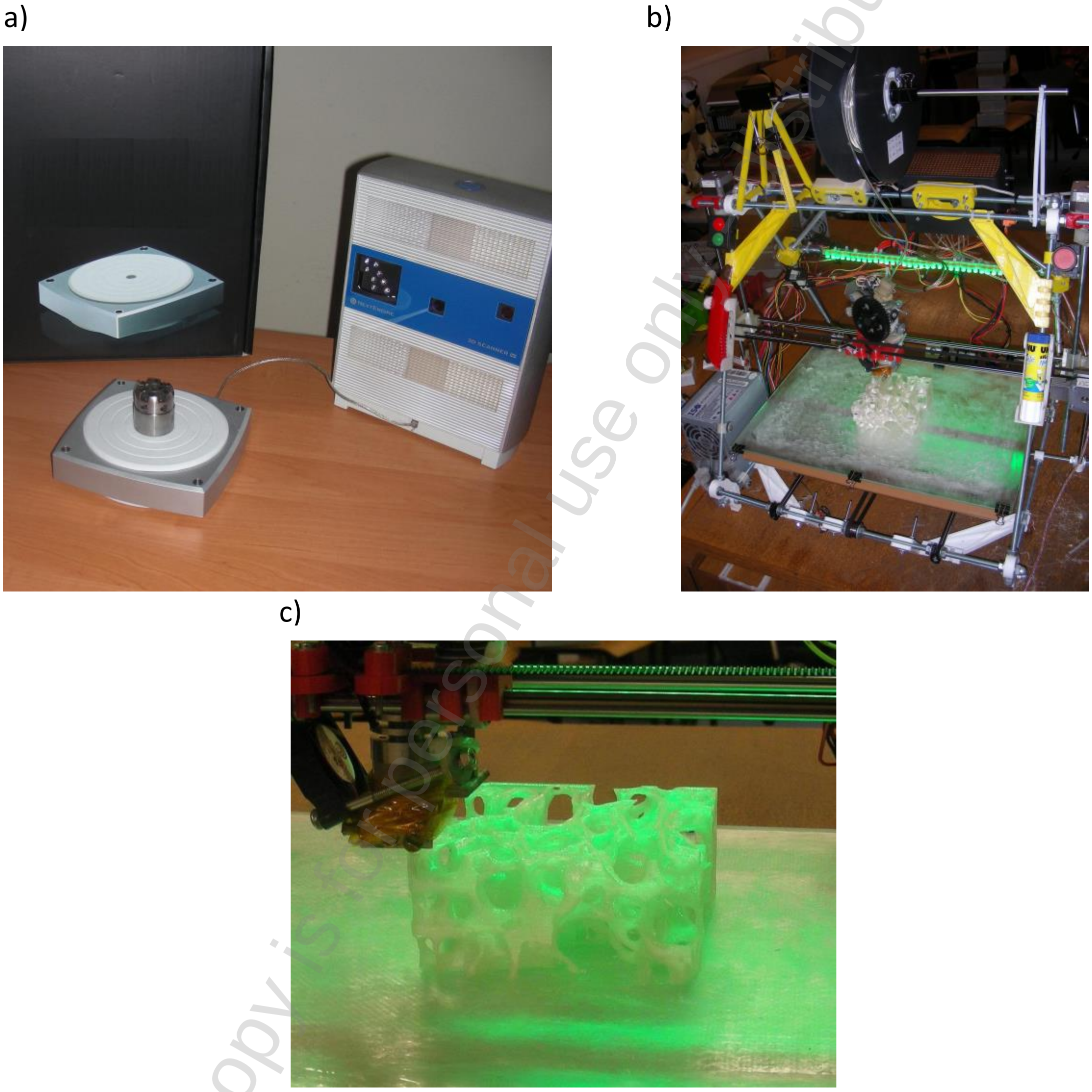

Fig. 2. Selected elements of the process of reverse engineering: a) 3D scanner; b) 3D printer at work; c) a printed element of a complex shape

Source: Photos by the authors

2. APPLICATIONS OF 3D PRINT AND 3D SCAN IN SECURITY AND DEFENSE OF THE STATE

Due to the early stage of development of 3D printing and 3D scanning technologies it is necessary to identify the areas in which 3D printing works best, and the others, where traditional technologies are better or only require modification. Currently, major perspective applications of the above technology in the field of security and defense are:

1. greater independence from supplies and fast, easy adaptation to current needs through:
   - shortening the supplies chain – it is enough to take a printer, documentation and part of the raw material, and consecutive printers and all equipment (including parts for construction and repair) are printed on the spot, partly of possessed raw materials, if it is cheaper and not less efficient;
   - lower production costs – due to shorter design and manufacturing cycles, the lack of the traditional tools for production, the minimum amount of production waste, possibilities for customization, short series and prototypes (like digital printing in polygraphs);
   - easier transport – due to less volume and mass of freight;
   - lower costs of storage;
2. the possibility to print personalized and better adapted to users' needs: clothing, weapons and equipment – from personalized sorts of uniforms and a soldier's individual equipment (involving easy adaptable camouflage) to guns and warheads;
3. the possibility of printing medical equipment and 3D bio-printing of skin and other organs, and hence: more effective health care system, the lack of discards due to soldier's stem cells used in printing;
4. printed food rations – food for soldiers and the wounded: balanced, individual printed diet for each of them, also heated and cooled products;
5. 3D models, realistic models of terrain and equipment, etc. combined with the technology of virtual reality and augmented reality, facilitating the presentation, assessment and orientation of the actual parameters based on the same model;
6. reverse engineering: rapid copying and/or modification of existing templates while developing protection e.g. against mass replication of weapons and parts thereof;
7. development of new materials such as steel, titanium, aluminum, and various types of plastics, and even chocolate (Choc Creator), printing electronic devices (conductive plastic *carbomorph*), changing their qualities under the influence of applied technology, the shape memory;
8. faster design, modification and personalization, innovative prototypes – cost savings in manufacturing devices existing in single copies;

9. the selection of technology and material for 3D printing, depending on the materials used, accuracy, complexity, etc.;
10. in some cases: the access to technology of manufacturing products unattainable through other methods;
11. development of recycling techniques (to a certain extent: of material self-sufficiency) [37].

In the USA there was established the National Additive Manufacturing Innovation Institute, and DARPA (the Defense Advanced Research Projects Agency) has created the program Open Manufacturing including research centers: the US Army Research Laboratory at Aberdeen Proving Ground (ARL MDF) and the Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-D3). Currently, research has been carried out on 3D printing from metal (for military purposes), in cooperation with the US Army Manufacturing Technology Program, the Federal Aviation Administration, the National Aeronautics and Space Administration and the US Army Evaluation Center. Requirements regarding final products mainly concern full functionality and safety. Translating the advantage of the above technologies into operational and tactical success may require not only technological and organizational changes, but also changes in military specialists' thinking and adequate staff training. In Europe, research on 3D printing using metal has been conducted by the ESA in the framework of the project 'Amaze' associated with space technologies, while NATO has been leading research on 3D printing, among others, under the project Science for Peace and Security (SPS), also on the security systems of 3D printing based on cloud computing.

3. PROBLEMS AND RISKS

At present the biggest issues to be tackled include:

– technological problems: the achievement of printed products' relevant parameters decisive for quality, durability, accuracy, performance, often resulting from the layer by layer production (now e.g. elements of plane wings have been already printed) or the loss of part of information about actual characteristics of the object surface (e.g. softness);

– security issues: changes in strategies based on technological leadership (especially in the defense and aerospace industry), the access by terrorists to the new 'garage' production method, a new aspect of cyber warfare (e.g. programmed defects of products or targeted attacks on the enemy's 3D printers);

– legal problems: copyright (what is an original and what is a copy; or parameters of a copy (durability, accuracy) may be intentionally weakened in order to ensure effective protection of copyrights);

– ethical problems: prolonging life, improving endurance, the exchange of organs 'upon request';

- social problems: the dispersion of industry, the collapse of large industrial centers, shifting the burden from workers to designers, change in trading and services strategies (the changing role of large corporations).

Important elements are continuous monitoring of dimensions, tolerance, matching and ergonomics in relation to the needs of specific applications as well as functional, strength and aging analyses. Aging processes or fatigue changes under loading may occur in printed elements differently than in other parts made using traditional methods (e.g. due to the lack of conventional joints).

Interdisciplinary nature of research in the field under discussion entails the need to create research teams of implementation specialists consisting of professionals from different areas, fields and disciplines. This is hampered by a shortage of research methodology, exploratory workshop and standardization of tools and products.

There is also a risk from overestimation of the potential of new technologies and tries to apply 3D printing wherever possible, while little knowledge about the impact of the passage of time on the parameters of printed products.

4. DEVELOPMENT DIRECTIONS

Due to the rapid development of the described technology the presented solutions are only the tip of the iceberg, no one knows its full potential and probably most of its limitations. Creating multi-element products from printed materials with different properties (e.g. electric conductors and insulators), which are, however, elements of the same project (the so-called *multi-material 3D printers*) lies ahead. Currently, power sources and electrical equipment appear the peak of possibilities herein, however, 3D printing technology may allow manufacturing devices which do not exist today and which have not been practically realized so far due to the lack of production technology. It is only a short step towards printing for example drones of shapes, dimensions and properties (including mask colors) adapted to the current needs. 3D printing can also provide new parameters of component density, assembly techniques and water-resistance of devices.

New production technologies of multi-agent systems with imprinted antennas and transmitter-receiver modes can create a completely new approach to reconnaissance.

The novelty are 4D printing technologies that allow programmed preservation of the printed elements depending on factors such as time, moisture, light, high or low temperature, weather conditions, etc., including the option of self-destruction (by the artificially reduction of the durability of the material) after a predetermined time. The so-called ‘smart materials’ are programmed in a way to change their properties, e.g. under the influence of intentional effect of the light. This will facilitate the repair and manufacturing spare parts on site.

Printing food rations mean the reduction of food waste, but also nutritional and prevention optimization. Technologies, *such as ultrasonic agglomeration to 3-D print small snack-type items* can allow for the production of pizza or casseroles. Powering printers with material for printing form standard trays makes them easy to use as 'field kitchens'.

The US Army has carried out research on the printed skin and blood vessels - they can be a breakthrough in the battlefield medicine.

The army from 3D printers may be cheaper, but it is not clear whether more effective. An important issue is fitting the above proposals into the environment and existing solutions. It is hard to assess how technologies presented will affect the tactics and strategy, but they are supposed to inevitably improve the logistic support of troops. They can also influence the balance of power by overcoming the current technological lead of some countries and the creation of a new kind of risks.

Development of 3D printing systems used for security needs of state defense systems is expected to result in the rapid development of systems weakening them at the same time (e.g. by purposeful introduction of software changes that slow the process of printing or reduce the usefulness of the final printed products), and combating and counteracting the effects of their actions (new measures damaging materials used for printing). The attack on logistic systems can have the same effects as direct attack on the troops, but at a lower cost.

CONCLUSION

The existing possibilities of 3D scanners and 3D printers are not fully utilized. This situation requires conducting separate studies on this group of technologies, involving interdisciplinary research teams. This is all the more important that it has a stimulating effect on other areas of research, enabling the development of subsequent devices using rapid prototyping.

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