3D PRINTING TECHNOLOGIES IN REHABILITATION ENGINEERING

Technologie druku 3D w inżynierii rehabilitacyjnej

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Abstract

3D printing, 3D scanning, and reverse engineering are relatively novel technologies, which may revolutionize scientific research within health sciences and clinical practice. Broader use of such technologies may cause developing customization/personalization of various medical products (including both equipment and drugs) and lower cost of design and manufacturing. This article aims at investigating the extent to which the available opportunities in the area of rehabilitation engineering are being exploited, including own concepts, studies and observations.

Introduction

Three-dimensional (3D) printing, 3D scanning, and reverse engineering are relatively novel technologies, which may revolutionize scientific research within health sciences and clinical practice [1-6]. Broader use of such technologies may cause developing customization/personalization of various medical products (including both equipment and drugs) and lower cost of design and manufacturing. This way more suitable, personalized medical treatment can in a significant way influence therapy outcomes.

3D printing can use various materials (plastic, metal, ceramics, living cells) in layers to produce a 3D object. There are many technologies, their features (speed, resolution) and materials, but general rule is the same: object is build vertically layer by layer allowing creation of the complex structures.

PubMed (U.S. National Library of Health) [7] database was searched to identify relevant articles in the area of applications of 3D painting, 3D scanning, and reverse engineering in rehabilitation engineering. This research was limited to the English language articles and encompassed the period from 01.01.1990 to 18.11.2014. Various keywords were used in the searches and frequency of specified keywords combinations, including „3D printer", "3D scanner", „reverse engineering", „rehabilitation", „physiotherapy", etc. Number of articles with aforementioned keywords seems be huge (275, 1996-2014, but "reverse engineering": 754 since 1990) for such novel technologies, and there is observed significant increase in the articles' number since 2009.

Many advances in rehabilitation and physiotherapy have been achieved as a result of advances in other fields, including rehabilitation engineering, medical IT, and robotics. This make rehabiltiation and physiotherapy open to novel approaches and technologies, which can increase effectivity of the theraputic interventions. 3D printing, 3D scanning and associated technologies can constitute another step toward better application of the rehabiltiation engineering principles in current clinical practice.

Aforementioned results show where studies on applications of aforementioned 3D techniques in rehabilitation engineering are concentrated now. This article aims at investigating the extent to which the available opportunities in the area of rehabilitation engineering are being exploited, including own concepts, studies and observations.

3D techniques in clinical applications

Current medical applications of 3D techniques cover many areas including:
- learning, including customized anatomical models, individual and team training in medical simulation centers,
- scientific research, concerning e.g. bones or soft tissues modelling and testing,
- 2D or 3D diagnostics (CT, MRI, clinical motion analysis, etc.) − 2D images can be converted to 3D images,
- 3D scanning (including fast face/head scanning and fast whole body scanning),
- 3D printing in surgery, drug fabrication, and rehabilitation engineering,
- reverse engineering (digitizing of real objects, partly for replication purposes),
- additive manufacturing, which allows for geometric flexibility of printed products (e.g. implants) and customisation to suit individual needs [8-17].

Traditional manual desing and manufacturing of personalized therapeutic solutions can be changed thanks to computer-aided desing (CAD), rapid prototyping (RP), and computer-aided manufacturing (CAM) of physical models or even final products directly from 3D computer data. Joining various methods and techniques (e.g. within reveres engineering) allows to significantly shorten track between measurements in particular patient and ready-to-use personalized equipment. Expensive, high-end 3D technologies are currently replaced by much chepaer commercial technologies that have proven much cheaper, offering the same quality, geometric accuracy, and shape reconfiguraton possibilities. Each 3D copy reflects the same original (or modified by therapists/manufacturer) data - there is lack of e.g. plastic mold or wrap destroyed irreversibly in the process of fabrication. Modification of geometrical parameters and

material features of the model or final product is possible on almost every stage of the manufacturing. In selected cases, where more specialistic knowledge and experience is required, rapid prototyping can be regarded only as quicker alternative for contemporary approaches. Another problem constitutes application of a proper materials in particular cases – there is need for development of novel materials for 3D printing, dedicated to the medical applications (e.g. in anti-allergic, water-resistant, non-fragile, etc.). Despite efforts of scientists traditional natural materials (wood, leather, metals) may be hard to replace, and there will be necessity to incorporate these materials. Thanks to digital technology general process can be unified to several stages:

- digital acquisition of the 3D geometric data directly from the patient (touch probe, laser-based, or a photographic-based scanning system) or based on his/her previous data file,
- digital model is stored on a computer,
- rectification and modification/adaptation procedures (on a computer, using specialized software), withou lost of the original (primary) data,
- creation of 3D model or even final product based on 3D printer or other computer numerically controlled machine (depending on the material, shape, etc.),
- control of the 3D model (including patient comfort).

Aforementioned processes, in selected cases, can be semi-automated. There is also need to admit, that RP has been previously regarded as quick and cost-effective method of creating nonfunctional prototypes only (e.g. with limited mechanical properties). This situation has changed recently, and some RP technologies can be used to create final products. Many technologies has been developed, including sterolitography, selective laser sintering (SLS), and Fused deposition modeling (FDM), and there is need for their careful assessment before use in aprticular medical application.

Current clinical applications in rehabilitation engineering

Basic clinical influence of aforementioned 3D techniques to diagnostics, therapy and rehabilitation is as follows:

- surgical planning - 3D scan data applied to production of accurate physical models,
- implants and prostheses, including personalized prosthesis' sockets [18],
- assistive devices (custom solutions, e.g. personalized keyguards and mounts),
- scaffold-based tissue engineering, ability to print tissues and organs that mimic nature in structure and function.

Patient-tailored therapy emphasizes necessity of individually shaped assistive technology solutions, provided using e.g. additive manufacturing [19]. Promising nerve repair techniques emerge for micro- and nanotechnology: microstructured scaffolds to promote regeneration, allowing to enhancement of regeneration using new tissue scaffold materials and architecture [20, 21]. This way nanostructured neural scaffolds and 3D-printed artificial substitutes make possibility for implantation and rehabilitation of injured nerves [21]. Use of 3D printing in surgical management and strategy of rehabilitation therapy of acetabular fracture makes accurate and safer surgical management of acetabular fracture, shortens postoperative recovery time, promotes postoperative recovery of the patient, and significantly decreases costs [22, 23]. As it was said before prototyping is useful tool for surgical planning and fabrication of prostheses and implants [24], including rapid prototyped biomaterials for tissue engineering applications [25]. Current technologies include customised foot orthoses (FOs) [26], computer aided prostheses and orthoses development (CAD/CAM Chêneau derivate has been called Gensingen brace) [27, 28].

3D pronting is useful in reconstructive surgery – it allows to reproduce/regenerate the exact nature of affected internal anatomy, eliminate potential errors, and decrease theatre/recovery time. Reconstruction of the internal anatomy is in these cases based on Computed Tomography (CT) and Magnetic Resonance Imaging (MRI). Using a mandibular stereomodel (physical models of mandible from computer-aided design via 3D printers) is faster, easier, and cheaper comparing to traditional approach [29]. Accurate 3D reproduction methods use 3D scanners (even, in selected cases, high-speed laser 3D scanners) and reverse enginnering software. Reverse engineering is commonly used in various dental technologies [31-35].

Directions of further research

Management strategies for many conditions, including severe neurological complications are still emerging. Further research in the area of 3D printing can cause emerging of new therapies and their optimization. Current evidences concerning their clinical use can be insufficient. Moreover all members of the multidisciplinary therapeutic team should be aware specific chances emerging from 3D printing. Wide discussed is use of reverse engineering to increase efficacy of rehabilitation.

There is need for further research, especially in the area of:
- enhanced interdisciplinary collaboration of various specialists (including engineers),
- dedicated graduate and postgraduate education of medical staff,
- strict clinical guidelines, ethical rules, and law regulations,
- novel printers, scanners, and software encouraging rapid prototyping,
- novel thermoplastic biomaterials with features desired for surgical handling, encouraging tissue (re)integration,
- hybrid or modular solutions, e.g. 3D printed devices with embedded sensors and effectors, constituting simple way of development for cheap hand prostheses,
- better integration of 3D printed solutions with existing approaches (need for standarization),
- biodegradable materials (where necessary).

There is also need for careful threats analysis and evidence-based medicine (EBM) approach to avoid possible secondary changes.

Conclusions

Problem of use of 3D printing, 3D scanning, and reverse engineering in rehabilitation engineering seems be underestimated. This situation needs separate research, assessment of associated technologies, and dedicated clinical guidelines, especially in case of 3D-printed assistive technology because use of such solutions are often associated with significant long-term disability and severe disorders (e.g. sensory or communication disorders).

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