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Research Article

Health 4.0 Oriented to Non-Surgical Treatment

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Abstract

The emerging technologies that are conforming the Industry 4.0 are also impacting on health. Artificial intelligence, 3D printing, robotics, big data, Internet of Things, augmented reality, among others, are adding a layer of digitization on classical processes, allowing to increase the effectiveness and efficiency in the processes related to health and opening a new space of possibilities. In this article, some examples will show the state of art of Health 4.0 in the non-surgical field.

Keywords: Industry 4.0; Artificial Intelligence; 3D Printing; Robotics; Big Data; Internet of Things; Augmented Reality

Introduction

"Industry 4.0" is the name of an initiative, initially proposed by the German government, which wants to take advantage of a renewed technological framework in which the use of different technologies (including robotics, artificial intelligence, cloud computing, Internet of Things, big data, additive manufacturing or augmented reality) aims to raise the production again competitive in countries with a long industrial tradition. From the application of the concepts associated with Industry 4.0, industry, and especially the manufacturing industry, is accelerating its automation process, adding a layer of digitization on the physical reality. At the end of the process, it is expected to achieve a highly efficient production environment, where the necessary human resources will be considerably smaller in number to the present ones, and with professional profiles and competencies re-quired that are very different from those that are needed today.

The concepts associated with Industry 4.0 are not exclusive to manufacturing production processes, but can be applied to areas as diverse as logistics, transportation, energy or health. Thus, the application of emerging technologies that imply the creation of a layer of digitization and aim to increase the efficiency in the processes related to health opens a new space of possibilities. Today it is possible to find multiple operational applications of what, in a non-original way, we can qualify with the label "Health 4.0".

Some Health 4.0 applications today

Robotics is deeply impacting on surgical treatments, but non-surgical treatments are also taking advantage of the emerging technologies. Without wishing to be exhaustive, some significant examples are presented in the following sections.

Disease prediction [1]

Heart attacks are hard to anticipate. In an effort to predict them, many doctors use guidelines similar to those of the American College of Cardiology/American Heart Association (ACC/AHA), based on eight risk factors, including age, cholesterol level and blood pressure.

The University of Nottingham (United Kingdom) has led an study com-paring the use of the ACC/AHA guidelines with machine-learning algorithms. First, they analyzed data coming from the electronic medical records of 378,256 patients in the United Kingdom. They used about 80% of the data to search for patterns and build their own internal "guidelines". Then they tested themselves on the remaining records. Using record data available in 2005, they predicted which patients would have their first cardiovascular event over the next 10 years, and checked the guesses against the 2015 records. Neural networks correctly predicted 7.6% more events than the ACC/AHA method, and raised 1.6% fewer false alarms. As prediction leads to prevention (through cholesterol-lowering medication or changes in diet) that would have meant lots of lives that could have been saved.

Diagnosis [2,3]

Since 2013 Watson, the IBM artificial intelligence system, dedicates part of its ac-tivity to support in decision making on cancer treatments, developing diagnoses and proposing a ranking of possible personalized treatments for each patient, ranked by applicability.

The system analyzes patient data against thousands of historical cases, information from more than 5,000 hours of training by oncologists, nearly 300 medical journals, more than 200 textbooks and 12 million pages of text.

After being initially tested at the Memorial Sloan-Kettering Cancer Center, several hospitals around the world today have access to the services of Wat-son for Oncology. The concordance of their diagnoses with teams of highly specialized oncologists exceeds 90%, and the time required to issue a diagnosis of high complexity has decreased from weeks to hours.

Mobile diagnosis [4,5]

Early 2017, after training with a database of nearly 130,000 skin disease images, computer scientists at Stanford Artificial Intelligence Laboratory have presented an artificially intelligent diagnosis algorithm for skin cancer. The final product was tested against 21 board-certified dermatologists. In its diagnoses of skin lesions, which represented the most common and deadliest skin cancers, the algorithm matched the performance of board-certified dermatologists.

Once the algorithm has been developed, since the diagnosis is based on an image, it is immediate to think of taking advantage of the photographic capacity of the smartphones to achieve to bring reliable skin cancer diagnoses ubiquitous. Thus, the developing team is already working on it.

The accessibility, intuitive user-interface and the inherent connectivity offered by smartphones can overcome the limiting factors of many point of care tests, creating new and exciting possibilities, a major revolution that will transform the patient experience and accelerate diagnostic decision making.

Remote medical care [6,7]

Sometimes, in rural or small hospitals a medical specialist is physically unavailable. In these cases, a robot can be deployed to check in on a patient with a physician from elsewhere.

Since 2013, the InTouch Vita robot aims to facilitate remote medical care. Includes built-in ports for diagnostic devices like ultrasound machines, stethoscopes, and otoscopes, plus two cameras and the ability to navigate autonomously in a non-structured environment.

New treatment plans [8,9]

In 2013, Stanford researchers identified a possible new treatment for small cell lung cancer, which is particularly deadly. The pipeline worked by scanning hundreds of thousands of gene-expression profiles (gathered by multiple researchers and stored in large databases) across many different cell types and tissues, some normal and some diseased, some treated with medications and some not. Alone, these profiles may not mean much, but when viewed together, they appear un-suspected patterns and trends. It came up that Imipramine, which is an anti-depressant, had the ability to help cure certain types of lung cancer. And because the drug was already approved by the Food and Drug Administration for use in humans, they'd been able to quickly and (relatively) inexpensively move into human trials.

Remote monitoring [10-12]

For years there has been interest in applications for remote monitoring of patients. For instance, in-home monitoring of vital signs of patients with chronic obstructive pulmonary disease provides more proactive care and makes healthcare more convenient and persistent. Up to now, these applications have been complex and expensive. Current availability and price decrease of sensors are facilitating the appearance of new products and services.

The Consumer Electronics Show (CES) in Las Vegas, the biggest consumer electronics fair in the world, is a great showcase of the new proposals either from established players and new start-ups. Some examples: HTC and Under Armour have presented a wrist-worn activity tracker designed for athletes and a chest strap heart monitor to measure workout intensity. Misfit introduced Specter, a pair of sleep-tracking headphones. GreatCall unveiled the Lively

Wearable, a device worn on the wrist or around the neck that tracks activity and offers a mobile emergency response service via a one-touch button that connects seniors to trained agents in emergency situations. L'Oreal teamed up with flexible electronics company MC10 created MyUVPatch, an adhesive patch users can apply to their skin and then consult a mobile app to track their UV exposure. Cercacor launched Ember, a finger clip sensor that measure pulse rate and hemoglobin, and connects to an app via Bluetooth. Omron debuted a new blood pressure monitor that also tracks activity and sleep, and connect to an app. Neogia offered a wear-able that detects sleep apnea and improves sleeping quality via a personalized artificial intelligence that learns about the user. TempTraq offered a patch-like smart device, which monitors body temperature 24/7. QardioCore presented hearth monitor without patches and wires to record continuous ECG, heart rate, heart rate variability, respiratory rate, skin temperature, and activity data, which can be shared with medical professionals. Bloomlife developed a "pregnancy wearable" that measures contractions and sends the information to a smart phone. Bodytrak presented a wearable that measures biometric information from the ear: body temperature, heart rate, VO2, speed, distance and cadence, continuously and in real-time.

Pre-surgical models [13,14]

3D printed pre-surgical planning models, based on patients' scans, are being used all over the world with the goal of improving accuracy and efficacy of complicated surgeries. 3D printed replicas allow physicians to evaluate and interact with patient anatomy in ways 2D images cannot, allowing unprecedented preparation for complex surgical cases as doctors are able to examine all angles before even touching a scalpel. Physicians know from first-hand experience that 3D printed patient-specific models improve surgery, improve outcomes and result in lower treatment costs.

While originally conceived of as a way to help surgeons with complicated or extremely delicate surgical procedures, doctors are discovering some unexpected benefits from using 3D printed replicas of patients' organs for surgical-preplanning for more common surgeries. 3D-printed anatomical models allow doctors to get a much clearer idea of their patient's internal anatomy, and make better treatment recommendations.

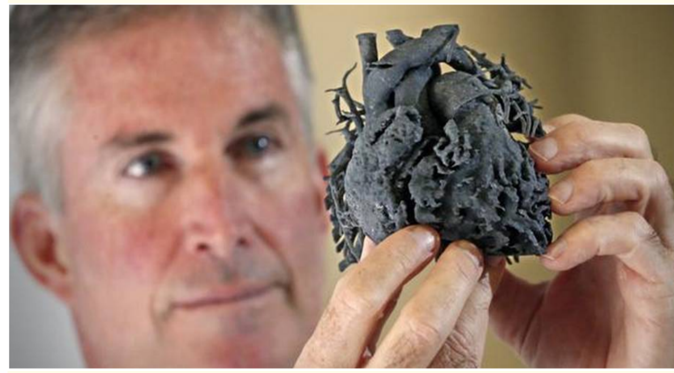

Figure 1: 3D printed heart (Source: 3dprint.com).

Implants [15-17]

In 2014, the first tests of replacements of knee and hip by 3D printed ones were completed. That year, Peking University Third Hospital's Orthopedics Department announced clinical trials of 3D printed artificial vertebral bodies. But dental pros-theses were the first to be introduced in a fully operational customized medical solutions. Thus, in 2015 the Catalan company Avinent Implant System had already passed the testing stage and regulatory issues and was offering its customized implant solutions by 3D printing. Today, they are offering a complete digital solution of personalized implants to hospitals and clinics in areas such as reconstructive surgery, orthognathic surgery, neurosurgery, panfacial fractures, condyle reconstructions, and reconstructions of any part of the body, such as the spinal column.

Implants have been used for decades. What is new is the way in which 3D printing allows the shapes of the orthotics to be created. There is an incredible flexibility in terms of the forms that can be generated. Rather than relying on boxy shapes that are easier to produce, the 3D printer's ability to create extremely complex geometries means a reduction in the amount of additional hardware necessary to force a generic implant to stay in place. Another benefit is the porous nature of the printed implant which allows bones to grow into the implant creating a natural bond. As with anything introduced into the body, these implants must be sterile and compatible with living cells. While it is a major challenge in the field, newer printable biocompatible materials are being developed for use in humans, some are synthetic polymers and some are derived from natural products like gelatin or seaweed.

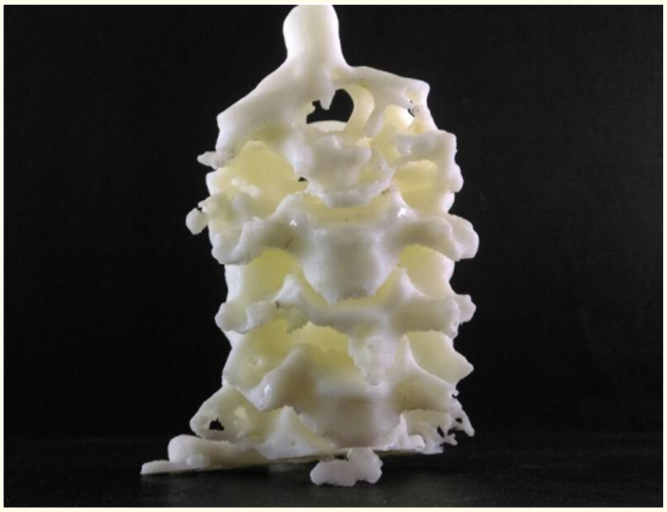

Figure 2: 3D printed heart (Source: 3dprint.com).

Organ printing [18-20]

With lots of patients on the waiting list for an organ transplant and a shortage of donated organs for transplants, organ printing is a promising revolutionary technology for saving human lives. The goal is to print a working organ that can be transplanted into a human, but according to the estimations of researchers, the ability to produce 3D printed complex organs is at least a decade away.

Meanwhile, printing living structures with bio-ink using a 3D printer is al-ready a reality. In 2014, the company Organovo delivered the first sample of its 3D bioprinted liver tissue. Today, bioprinted lung, liver, skeletal muscle, cardiac, blood vessel, skin, bone, cartilage and nerve tissue are available. These tissue samples can be used by pharmaceutical companies in toxicology tests of new drug candidates.

It is also possible to create structures like ears or noses. In 2016, Wake Forest Institute for Regenerative Medicine unveiled its system that allows, after a couple of months, to naturally form cartilage tissue and blood vessels into those bioprinted structures. But it will take a while to start trials in humans.

Minimal invasive interventions [21,22]

Nanorobots have huge potential for application in medical robotics, for which they offer accuracy in their performance of operations along with minimal invasion of the patient. Researchers from Johns Hopkins University are developing "soft" robots with microgrippers that are capable of adhering to specific body tis-sues. These could be used in extraction procedures for biopsies or for the localized injection of drugs. In another area, researchers from the University of Bristol are studying how swarms of nanorobots could detect cancer cells and carry out non-invasive surgical interventions at cellular level in patients with tumors. For their part, researchers from the Swiss Federal Institute of Technology in Zurich (ETHZ) are working with nanorobots magnetically guided to carry out eye operations on patients with cataracts and glaucoma.

Surgical support [23,24]

The team of Dr Itaru Endo, head of the department of surgery of the digestive tract and liver transplantation of Yokohama City University, in collaboration with the Fraunhofer MEVIS, has developed a machine-vision system, based on an iPad app, to give surgical support in liver operations. The application, which is now being clinically evaluated, gives access to three-dimensional surgical data. Thanks to augmented reality techniques, during the operation images of the vascular system are superimposed so as to allow the pattern of blood circulation in the liver to be discerned, which would otherwise be invisible to the naked human eye. The application also shows the areas of blood flow and assesses the potential risks in real time.

Figure 3: Fraunhofer iPad app guides liver surgery through augmented reality (Source: www.engadget.com).

Sample processing [25]

Classical industrial robots are already present in laboratories, either for the processing of samples, for the preparation of drugs dosages, or for preparing case-work DNA samples. These activities need multiple steps that, when done with manual workflow, are tedious. Robots can automate most, if not all, of this processes. That allows to improve efficiency, save time, reduce human error and improve documentation, enabling to focus on analysis and interpretation rather than process tasks.

Prosthetics [26,27]

3D printing and open source platforms are helping to engender low-cost prosthetic devices that users can buy at a fraction of the cost of traditional commercial prostheses. These prostheses may have reduced functionality, but they represent a clear advantage over traditional non-movable prostheses. In the open source domain, pure magic can happen when designers, experts in robotics, makers, and owners of 3D printers get together to bring robotic prostheses to people who otherwise could not afford them, and especially to children.

The e-NABLE project involves a community of more than 3,200 people who have already created more than 700 prostheses for users all over the world. The designs are intended to be as functional as possible, rather than to mimic the human limb, and can be customized to suit individual needs (fingers, feet, whole arms, elbows...). The "Hand-o-matic" software allows the user to design his or her own prosthesis and to obtain the data files for its 3D printing, which they can do themselves or get another person in the community who has a printer to do for them.

Figure 4: 3D printed prosthetic hand (Source: enablingthefuture.org).

Rehabilitation and mobility aid [28-30]

The first working medical exoskeleton was created in 1972 by the Mihajlo Pupin Institute in Belgrade, Yugoslavia. Although several labs demonstrated early success with exoskeleton development for medical use, research in industrial robotics was far more practical and profitable. It wasn't but decades later when exoskeleton development was restarted.

There are two main categories of medical exoskeletons: rehabilitation and mobility aid. A rehabilitation device is used as a tool to augment a physical rehabilitation program and is no longer used after the completion of the program. A mobility aid wearable will be used permanently and the user is not expected to progress in the recovery process. In this case the exoskeleton becomes an augmentative device.

As examples, the Ekso GT by Ekso Bionics has to be used by a person that still has some mobility and the user has to be able to shift weight from one leg to the other (its software allows a gradual decrease in the assistive force as the patient becomes stronger during rehabilitation). In contrast, the REX by REX Bionics takes full control of walking, including transferring weight from one leg to the other, so its operator “rides” the suit and does not use their own muscles to walk.

Although with less presence in the market, there also exist upper body exoskeletons, focusing on the arm (shoulder, elbow) or hand (fingers, wrist) with strengthening or augmentation functions.

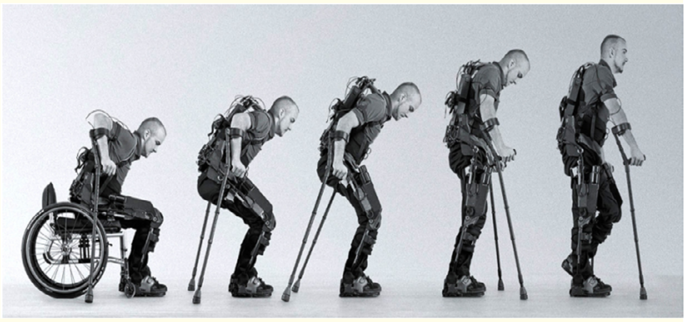

Figure 5: Mobility exoskeleton (Source: www.medicaltourismitaly.com).

Assistive solutions [31-34]

Robotics is proposing solutions to make life easier for people with disabilities. The company Whill has gone beyond the concept "Wheelchairs" to introduce the "Personal electric vehicle". Robot Care Systems has created LEA (Lean Empowering Assistant) an elderly-walker that provides support to more active and safe movement, so elderly can live longer independently in their own home. Camanio Care focus its activity looking for positive mealtime experience for elderly or people with different disabilities, offering assistive eating and drinking aids like Bestic and Drinc.

In the field of support for people with neurological disorders there is an extensive collection of advanced interactive robots. For years, robotic teddies looking like seals, dogs, cats, bears or rabbits are helping in the treatment of patients with autism or Alzheimer. For instance, since 2003 PARO stimulates interactions and improves the socialization of patients.

Figure 6: PARO (Source: www.parorobots.com).

Delivery transport [35,36]

Hospitals move an immense amount of materials through hallways, on elevators, in basements and to patient units. This is a complex and demanding internal logistics challenge that has implications on costs, quality and safety. Automating de-livery of this material generates considerable savings, efficiency and worker satisfaction, because if robots perform the delivery and transportation tasks they re-lease clinical and service staff to focus on patient care.

One of the first was UCSF Medical Center at Mission Bay, that in 2017 incorporated a fleet of 25 autonomous robots made by Aethon for the transportation of medicines, medical equipment, bedding, food and waste. These robots have an integrated mapping system to orient themselves wherever they might be on the premises and they communicate with the hospital information systems by means of Wi-Fi. Their infrared and ultrasonic sensors help them to avoid collisions and they use radio waves to open the doors of elevators, which they can only use if they are empty of people.

Figure 7: TUG (Source: www.aethon.com).

Economical efficiency [37]

The current evidence shows that for most patients, all drugs from a class called statins used to prevent cardiovascular problems are equally safe and effective, so doctors are usually advised to use the cheapest.

In a project that cost almost nothing to build, by doing one simple analysis on publicly available NHS prescriptions data, Mastodon C, a big data start-up company, found that in one year in England an average of £27m a month of potentially unnecessary expenditure on the two proprietary statins took place. As Sir Bruce Keogh, Medical Director of the NHS Commissioning Board, said: "Variation in prescribing habits costs the NHS millions of pounds a year. Transparent sharing of information will help clinicians understand whether they are over or under prescribing. This will focus minds in a way that will not only improve the quality of treatment for patients but also reduce cost and free up money for re-investment in other parts of the NHS".

Conclusions and Further Developments

The examples previously presented are only a few examples of what these technologies will allow us to do over the next decade, which will bring about a revolution in the field of medicine. We won't have to wait longtime to see achievements today only featured in sci-fi.

But Health 4.0 is not only a technological issue. Legal and ethics aspects will have to be faced with an open mind but in a very strict way: the border be-tween what will be feasible and what acceptable too often won't be clear.

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