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Review

Robots in Health and Social Care: A Complementary Technology to Home Care and Telehealthcare?

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Abstract: This article offers a brief overview of most current and potential uses and applications of robotics in health/care and social care, whether commercially ready and available on the market or still at the various stages of research and prototyping. We provide carefully hand-picked examples and pointers to on-going research for each set of identified robotics applications and then discuss the main ingredients for the success of these applications, as well as the main issues surrounding their adoption for everyday use, including sustainability in non-technical environments, patient/user safety and acceptance, ethical considerations such as patient/user privacy, and cost effectiveness. We examine how robotics could (partially) fill in some of the identified gaps in current telehealthcare and home care/self-care provisions. The article concludes with a brief glimpse at a couple of emerging developments and promising applications in the field (soft robots and robots for disaster response) that are expected to play important roles in the future.

Keywords: robots; robotics; telehealthcare; Ambient Assisted Living; assistive technology; social care

1. Introduction

Robots serving various tasks and purposes in the medical/health and social care sectors beyond the traditional scope of surgical and rehabilitation robots are poised to become one of the most important technological innovations of the 21st century. In this article, we offer a brief but rather comprehensive overview of most of the current and potential uses and applications of robotics in health/care and social care. We cover solutions at different stages of development, whether commercially ready and available on the market or still at the various phases of research experimentation and prototyping. We provide carefully hand-picked examples and pointers to on-going research for each set of identified robotics applications and then discuss the main ingredients for the success of these applications, as well as the main issues surrounding their adoption for everyday use. We examine how robotics could partially fill in some of the identified gaps in current telehealthcare and home care/self-care provisions. We conclude with a brief glimpse at a couple of emerging developments and promising applications in the field that are expected to play important roles in the future.

Readers should note that this paper is intended to be read mainly by non-roboticists, with little or no former background in the field. Specifically, the paper is meant as an "eye opener" for conventional health informatics and telemedicine/telehealthcare specialists and clinicians, who might not be very familiar with, or experts in, robotics, but are still very much interested to learn (in a simplified language) about it, particularly about how robotics may help users in the health, healthcare and social care sectors.

2. Overview and Classification of Current and Potential Robotics Applications in Health/Care and Social Care

2.1. Traditional Specialised Medical Robots: Robots for Surgery (Telerobotic Surgery) and Rehabilitation

Traditional medical robots as reviewed by Beasley [1] have focused mainly on highly specialised platforms for surgery or rehabilitation and low levels of autonomy, relying on tele-operation and/or the presence of qualified staff to enable and ensure appropriate conditions and use. Examples include the Neuromate robot [2] for stereotactic neurosurgery, and the da Vinci robot [3], which provides visualisation as well as enhanced dexterity to surgeons during laparoscopic surgery. The Neuromate robot was the first robot to offer support for stereotactic interventions, using image registration techniques to provide rapid and precise navigating and targeting. The robot consists of a single high-precision robotic arm and a physical frame in which the patient can be fixed. The da Vinci robot facilitates laparoscopy procedures by providing the surgeon with improved visibility and control. The system is operated by the surgeon from a dedicated control unit, and the patient is situated underneath a second unit with multiple robot arms, equipped with relevant instruments and controlled by the surgeon. Both the Neuromate and da Vinci robots are well established technologies and have been used for thousands of procedures. Other examples of highly specialised robotic systems include the different stroke impairment rehabilitation aids reviewed by Hidler [4], such as the ARM-GUIDE for facilitating arm movement exercises and the Lokomat gait orthosis, which facilitates walking exercises. The ARM-GUIDE robot is a 4 DoF (Degree of Freedom) frame that, when attached to a patient's arm, can be used to produce and record motions of varying rotations, translations, forces and speeds. The patient is typically seated in a fixed position next to the floor-mounted robot. The Lokomat robot consists of a frame mounted around a treadmill. The frame contains a weight-bearing structure as well as a gait orthosis that, when attached to a patient, controls both hip and knee joints, producing pre-defined gait patterns. Recent work that also falls into the category of specialised platforms for surgery or rehabilitation includes the Veebot [5], a highly specialised system for autonomously drawing blood samples from humans, and the hybrid assistive limb (HAL) [6], a wearable orthosis that has allowed post-stroke hemiplegic patients to exercise without requiring environmental support during rehabilitation. A novel approach along these traditional lines is the magnetic microbots for vascular network intervention [7]. These microbots can be remotely controlled while in the vascular network, e.g., for targeted delivery of drugs.

2.2. An Emerging Class of Versatile and (Usually) Less Costly Robots Supporting "Softer" Human-Robot Interaction Tasks

A recent trend has been to move away from costly, task-specific platforms supporting well-defined medical, commonly surgical tasks, towards cheaper more generic platforms, such as the Giraff mobile robot [8] or the Nao small humanoid robot [9] (Figure 1).

Figure 1. Plymouth University researchers, including the corresponding author on this paper, during a demonstration of Nao programmable humanoid robot (by Aldebaran Robotics, Paris, France) [9] to MPs (Members of Parliament) at the House of Commons (UK Parliament) in London on 5 September 2013. (Photo is meant to show Nao's size relative to that of adult humans).

These robots can commonly support a number of different and "softer" human-robot interaction (HRI) tasks and have been used to improve the medical conditions of patients. However, they have also been successfully applied to a range of tasks that do not address medical conditions directly. Instead, these latter applications have focused on generic health and quality of life issues, as well as issues related to social care. Below we review work that fits this modern trend of HRI-based robotics for health and social care. Our review focuses in particular on the areas of assisted logistics, therapy and HRI for general health and wellbeing. We also review work that studies the relationships that form between the humans and the robots in these situations.

2.2.1. Robots Providing Assisted Logistics in Hospital and Care Home Environments

Robots have been applied in multiple ways to assist the logistics of health and social care. The applications include hospital and care home environments and range from specific solutions addressing relatively well defined problems, such as the Bestic feeding robot [10], to generic solutions, such as autonomous courier robots, e.g., the Atheon TUG platform [11], and generic human handling robots that themselves have humanoid physiologies, e.g., the Cody platform [12]. Below we give a few examples of robots providing a logistic service as a broad class and cover their readiness (commercial availability) for deployment in real world healthcare institutions.

Within a hospital environment, robots, such as the HelpMate [13] and the Atheon TUG [11], are established solutions that provide autonomous transport of materials and supplies to support nursing staff. These solutions use traditional mobile robot technologies, such as proximity sensors for obstacle avoidance and path planning for navigation, in order to safely navigate semi-structured environments, e.g., hospital wards. On-going research on robots, such as RI-MAN [14] and Cody robot [12], tries to provide more specialised support to assist nurses in physically handling patients in a way that is more intuitive and flexible than existing patient handling technologies.

Unresolved issues for these platforms are: patient safety, as the robots are necessarily quite powerful and rigid; efficient control, as the control of a humanoid body requires coordination of tens of degrees of freedom; and appropriate levels of autonomy, as high autonomy can facilitate control, but may reduce patient safety. The research on the Cody platform has explored a tactile interface to facilitate control through physical interaction [12]. Research on the RI-MAN platform has explored the effectiveness of a soft, touch-sensitive covering to improve patient safety [14]. There is also on-going research on providing automated transport of patients in the form of autonomous wheelchairs [15]. This work focuses particularly on safe and reliable navigation in terms of stable trajectory encodings. Finally, a task-specific robot, Bestic [10] provides support by feeding a patient. The research on Bestic focused on the experience of the user and what the user would want from it, in particular in terms of aesthetics and social isolation or freedom. The Bestic robot is currently commercially available.

2.2.2. Telepresence (Video Conferencing) and Companion Robots in Home and Hospital Settings

Non-tactile HRI has also been studied extensively in the health and social care domain. Verbal and gesture-based interaction provides opportunities for robots to support patients in two main ways. First, a robot can act as a conduit for socialising, enabling friends or family to engage with the user remotely, or for (remote) communication with a health professional, allowing professionals to reach a larger number of patients. Second, a robot can present itself as an autonomous entity, providing play scenarios that can reduce the effect of disabilities, or improving wellbeing through entertainment and companionship.

Both the GiraffPlus [8] and the RP-VITA [16] robots are mobile platforms that provide video conferencing capabilities to support doctor-patient interaction, as well as additional patient-side measurement capabilities. The work on GiraffPlus has studied the integration of a mobile video-conferencing platform in an environment that also contains other tele-health sensors, monitors and alarm systems, providing advantages such as an improved probability of early detection of health deterioration [8]. The work on the RP-VITA platform has focused on studying the view of such systems in a surgical intensive care unit [16]. Both these platforms have been deployed and tested in their intended environment and both are commercially available.

Work with the Paro robotic seal by Wada and Shibata [17] demonstrated that the robot's mere presence increased social interaction and reduced the stress on the subjects' vital organs during an experiment in an elderly people's care home. The Paro seal was a very simple robot covered in fur and with simple behaviours such as looking towards loud sounds and sleeping at regular intervals.

2.2.3. Humanoid Robots for Entertaining, Educating and Improving the Communication Skills of Children with Special Needs

Several studies have looked at autism spectrum disorders, providing robot therapy that improves the social and communication skills of children with these or related disabilities. Robins *et al*. [18] developed a methodology, based on extensive experience with the bespoke Kaspar robot, whereby appropriate robot-based play scenarios can be developed depending on disability type and skill area to be stimulated. Bekele and colleagues [19] focused on developing realistic communication behaviours, in particular head tracking for the robot to indicate its engagement in the on-going interaction.

Csala *et al*. [20] studied the effectiveness of a tele-operated Nao humanoid robot (Figure 1) in improving the wellbeing of children having undergone marrow-transplants. Due to the nature of their operations and their immunocompromised state, the children have to spend a period of time alone in a 2 m by 3 m sterile room. The study demonstrated that the Nao robot is well suited for this task due to its small size and robustness. The study also identified personalisation as a key requirement for success. Belpaeme *et al*. [9] took a similar approach, using a Nao robot as a tool to entertain and educate children suffering from diabetes in a hospital environment. This work focused on providing high levels of robot autonomy through a natural language interface and a long-term memory structure that allowed children to develop a personal relationship with the robot. Both studies by Csala *et al*. and Belpaeme *et al*. took place in hospitals and both efforts were greatly appreciated by the children involved.

2.2.4. Robots as Motivational Coaches (Persuasive Robotics)

Another possibility to improve people's quality of life is to use robots in the role of a coach, providing motivation for healthy living, diet and exercise. This approach has been studied by several research groups. Comparative results from Kidd and Breazeal [21] suggest that participants in a dieting experiment tracked their calorie consumption for nearly twice as long when using mini robots (Autom^{TM}—Figure 2) than with the other methods, indicating that this is due to the stronger personal relationship with the Autom™ robot. Siegel *et al*. [22] in their work on Persuasive Robotics studied the role of gender in the effectiveness of a robot to elicit charitable donations. Results indicated that a robot of the opposite gender is more likely to elicit donations. Fasola and Matarić [23] also studied robots acting as coaches. Their work developed a set of design principles and robot qualities for success that can be summarised as motivating, highly interactive, personable, intelligent and task-driven. The principles were derived from, and evaluated on, a range of workout and memory games.

Figure 2. Approximate relative sizes of Autom™ (**left**) and Giraff (**right**) robots compared to that of an adult human. Autom™ is a mini robot while Giraff is as tall as a standing human (figure created in photo edited by the authors).

2.2.5. Home Assistance Robots for an Ageing Society

Yamazaki and colleagues [24] developed a home assistance robot that can serve as home-assistant to improve the quality of life in an ageing society. The work systematically identified relevant tasks and assistive technologies in order to provide pertinent and prioritised support for older people. Many of the issues identified were addressed, but some of them, e.g., object manipulation in an unstructured environment, are very complex questions that have been the focus of much research in the robotics community for decades.

2.2.6. Human-Robot Relationships in Medical and Care Situations

A growing number of studies are looking at experiences related to the use of robotics for health and social care. Below we briefly present work that investigated the relationships that form between humans and robots in medical and care situations.

Frennert *et al*. [8] studied elderly people's perception of a telehealthcare system (with a robot component—GiraffPlus) in terms of advantages, compatibility, complexity and observability. The study concluded that the crucial factor for adoption was the system's ability to support autonomy in everyday life. The researchers studied the use of the integrated GiraffPlus system by elderly people in a laboratory setting. Study participants were taken through a scenario whereby they had to communicate with a nurse and a physiotherapist after having returned back home following a period spent in hospital. Overall positive attitudes with significant sceptical elements were reported for all the terms studied.

Belpaeme and colleagues [9] studied the personal relationship between Nao robots and hospital children suffering from diabetes. User modelling, memory structures and emotional body postures were all used to promote such relationships to better engage the children in a learning process. The robots were also personalised according to a personality assessment of the child. In questionnaires, the children reported that they wanted to play with the robot again, even after repeated sessions when the novelty had worn off, indicating the establishment of a personal relationship with the robot. A more objective investigation into the level of empathy between humans and robots was undertaken by Rosenthal-von der Pütten *et al*. [25], who conducted an fMRI (functional magnetic resonance imaging) study of human subjects being shown videos containing violence against humans, robots and inanimate objects. Both the videos about violence against humans and those depicting violence against robots elicited activation in the limbic structures, indicating similar emotional reactions, though the negative concern for humans was higher than that for robots.

3. Discussion

Robots come in different forms/form factors to serve various purposes, tasks and applications in the medical/healthcare and social care domains. The range of robotic applications that are available for these latter domains is extremely vast, diverse and continually growing all the time, from robots used in minimally invasive robot-assisted surgery and in rehabilitation, to robots designed to function in hospitals/care homes and personal robots serving as motivational coaches or assisting older people with housework and domestic chores. Besides serving the needs of older populations, robots have shown to be equally successful in applications targeting paediatric age groups. Some of the robotic systems, applications and solutions we covered in our brief review are ready today and commercially available for real-world deployment and everyday use, while others are not yet fully mature and/or commercially viable, and remain at the time of writing this text in the confines of research laboratories at various stages of research prototyping and experimentation. Table 1 summarises the main highlights from our brief overview and attempts to classify the scope of robotic systems and applications in the medical/healthcare and social care domains and some of the related robotics research.

Table 1. Classification of the main robotic systems and studies consulted in preparing this paper.

- **Applications/tasks**
    - *Tele-surgery*
        - Neuromate stereotactic robot [2]
        - da Vinci [3]
        - Vascular network intervention [7]
    - *Rehabilitation*
        - Stroke impairment robot devices [4]
        - Post stroke hybrid limb [6]
    - *Treatment*
        - Drawing blood (Veebot robotic phlebotomist) [5]
    - *Assisted logistics*
        - HelpMate [13]
        - Logistics [11]
        - Nurse assistant [12]
        - Autonomous wheelchair [15]
        - Eating aid robot (Bestic) [10]
    - *Therapy*
        - Autism [19]
        - Marrow-transplant children [20]
        - Disabilities [18]
        - Professional telepresence [16]
        - Social Interaction [8]
    - *Generic health and wellbeing*
        - Elderly care/care homes [17,24]
        - Home assistance/housework [24,26]
        - Diabetes education for children [9]
        - Coaching
            - Persuasive Robotics [22]
            - Robot weight loss coach (Autom™—Figure 2) [21]
            - Robot exercise coach [23]
- **Experiences**
    - Perception (older people) [8]
    - Bonds (children) [9]
    - Empathy [25]
    - Installation (hospital) [27]
    - Requirements (nursing homes) [28]
- **Capabilities**
    - Automated attention to subject [19]
    - User modelling [9]
    - Long-term monitoring [8]
    - Learning [29]

Table 1. *Cont.*

• **Commercialisation**
○ Atheon TUG, Anybots, RoboCourier, RP-Vita [16], Giraff [8] (Figure 2), and others
• **Platforms**
○ *Stationary* ▪ Neuromate [2] ▪ da Vinci [3] ▪ Bestic [10] ○ *Mobile* ▪ Atheon TUG [11] ▪ HelpMate [13] ○ *Mobile with screen* ▪ Giraff/GiraffPlus [8,30] ▪ RP-VITA [16] ○ *Mobile with arms* ▪ PR2 [26] ▪ IRT [24] ○ *Animals* ▪ Paro (seal) [17,31] ○ *Humanoid* ▪ iCub ▪ Nao (Figure 1) [9,20]

3.1. Ingredients for Success

When adequately designed and where properly deployed, robots can streamline and make more efficient the tasks and processes they are targeting, and help improve effectiveness and outcomes. The Kiva industrial robots employed in the warehouses of major retailers are a good example of such benefits. The medical, health and social care domains are rapidly catching up with robotics technology, despite their very much more complex settings and demanding requirements (compared to retailer warehouses, *etc*.).

3.1.1. General Desiderata in Successful Robotic Solutions

General ingredients for success include:

– Adequate personalisation, where applicable, to match different user types and even individual patient/user profiles;
– Appropriate (safe) levels of robot autonomy in various use scenarios;
– Proper object manipulation and navigation in unstructured environments for those robots handling such tasks;
– Patient/user safety;
– Reliability and robustness, e.g., the availability and automatic triggering of proper contingency plans and mechanisms for robots that are remotely controlled over the Internet, to continue functioning safely when their main Internet connection is broken for whatever reason;

- Sustainability, particularly in non-technical environments (patients' homes are not high-tech facilities with resident technicians, and might be located in very distant areas that cannot be quickly or easily reached by technicians; where applicable, systems should be configurable and fixable over the Internet); and
- For robots serving motivational and/or social purposes, they additionally need to be personable, intelligent and highly interactive.

Some robots are quite powerful and rigid, but this needs to be balanced with fine "dexterous" capabilities for a more careful negotiation and manipulation of their environments and the obstacles and objects therein. For example, a robotic prosthetic hand must adapt its grip pressure according to the varying nature of objects it is handling, so that, for example, it does not crash a delicate egg when holding/carrying it.

3.1.2. User Acceptance and Ethical Issues

Usability and user acceptance are extremely important for the success of any robotic solution, particularly socially assistive robots that are designed to help older people live independently longer in their homes. The ideal robotic solutions must cater for any unique individual user needs and take into consideration users' socio-demographic profiles (and again what the latter imply in terms of associated specific user requirements that have to be addressed) [32]. Sharkey and Sharkey [33] list some additional issues of ethical nature in robot care for older people that must be adequately addressed or mitigated in any successful robotic solution targeting this age group; these concerns include (i) the potential reduction in the amount of human contact that the older person receives; (ii) social isolation, deception, loss of dignity and infantilisation of the older person; (iii) the increase in the older person's feelings of objectification, loss of control and loss of personal liberty; and (iv) the loss of individual and household privacy (e.g., with remotely controlled video conferencing robots, such as Giraff, transmitting a live video stream from patient's home).

3.1.3. Robotiquette and Robots that Learn

Humanoid robots usually have to respond to, and interact with, their target user/owner and possibly other people in their environment, and have to do so in a socially intelligent and convincing way ("robotiquette" [34]); for example, follow or pay attention to a talking person by moving robot's head/eyes towards the person's direction, to show interest and as a sign that the robot is listening; move robot's arm to greet people and elicit other responses and expressions using the robot's face/body as appropriate; be tolerant to faults made by the human user and gracefully respond to them where/as appropriate; recognise the face and voice of human user(s); and engage in human-robot conversations, responding by natural talking via embedded text-to-speech technology. This socially intelligent and adaptive behaviour of humanoid robots is key to establishing a positive personal bond between the human user as seen in experiments involving Nao [9,20]. Some robots may even need to learn from past experiences and encounters, similar to what we humans do all the time, although it is relatively early research days for learning robots, which are still (as of 2013) struggling to master the general learning levels of a human toddler.

3.2. Cost and Workforce Issues

3.2.1. How Cost Effective Is a Robotic Solution (Costs per Unit, Running Costs and Cost Justification)

Cost is usually a decisive factor when choosing and deploying (new) products and solutions in the health/care and social care sectors. The per unit cost of robots and robotic solutions intended for the latter sectors varies extensively, from about £125.00 GBP for the Autom™ weight loss robot (plus a monthly subscription to the corresponding Autom™ service of about £10.00 GBP/month for a minimum of 12 months), to £4,000.00 GBP for Giraff (Figure 2), £200,000.00 GBP for RP-VITA [16], and very much more than that for some other robotic systems (e.g., £1,500,000.00 GBP for some robotic surgical systems [35]). Additional installation and essential hospital/home environment modification costs, as well as recurring (running) costs must also be taken into consideration; for example, repair/maintenance costs, subscription fees (e.g., Autom™), broadband Internet connection (for remotely controlled robots) and power consumption/consumables costs (e.g., the costs of replacing the lithium-ion batteries that are used to power Nao, when battery health deteriorates), depreciation/recycling and replacement/upgrade costs, any technical staff costs (many robotics systems come with significant related personnel costs for operation and/or maintenance that can equal or exceed the cost of the robot platform itself), costs of insurance against liability/injury and equipment damage or loss, *etc*.

Cost justification (e.g., savings introduced by using robots, improved clinical outcomes and quality of life, and reduction of care costs, *etc*.) and ROI (return on investment) must be carefully considered in any procurement/business plan of robotic solutions. For example, the very high costs of robotic surgical systems may be partially offset or balanced by their positive attributes, which are unique to such systems and highly desirable by both surgeons and patients [36].

3.2.2. Cost Saving Approaches: Modelling in Virtual Worlds and Using Virtual Robots

Moon *et al*. [37] proposed using multi-user virtual worlds such as Second Life as a modelling platform for pilot testing of medical robots and their user interfaces prior to physical development to identify any problems, bottlenecks, *etc*., and as a way to reducing prototyping and deployment costs. Indeed, the corresponding author was involved a few years ago in a quite promising modelling exercise of telehealthcare sensors in Second Life [38], and can testify to the potential of virtual worlds in this respect.

Encarnação and colleagues [39] investigated the use of virtual robots running in an on-screen simulated environment (*vs*. physical robots) for assessing children's cognitive skills. They concluded that virtual robots were a viable alternative in their case to the use of physical robots, and that virtual robots have the potential of overcoming some of the limitations of physical robots such as cost, reliability and the need for on-site technical support. Of course, only some applications/application scenarios are amenable to such a solution involving virtual robots (for cost reduction purposes). For example, Autom™, the weight reduction robot (discussed below), might be replaceable with a virtual robot running on a smartphone or tablet (although Siegel and Breazeal [22] are suggesting that the physicality of a robot is a significant factor that cannot be equalled by virtual alternatives), but the task of physically feeding a patient as performed by Bestic [10] will never be possible using an on-screen virtual robot.

3.2.3. Impacts on the Workforce and Skills Shortages

The societal impact of robots on the workforce is also a matter of study and debate. Robots are sometimes touted as part of the solution to the chronic workforce and skills shortages in the health/care and social care sectors, but they are sometimes equally blamed for cutting job cuts, particularly non-technical/non-highly-skilled jobs. On the other hand, robots often create the need for new highly technical jobs that are required to research and support the building, programming, deployment and maintenance of successful robotic solutions. Skills shortages in these latter areas are not uncommon, and might present a potential barrier to the successful and widespread adoption of the technology. (For example, despite the featuring some degree of autonomy and self-adaptation to its environment Nao [9,20]. Figure 1 still requires dedicated technical personnel behind the scenes for programming and remotely controlling the robot.).

For robots performing housework, domestic chores, or companion/assistant and babysitting tasks, it might be wise to consider the cost effectiveness (or non-effectiveness) of using robots, any associated risks, job cuts or new technical job creation, skills shortages in relation to the latter, *etc*., the impact that all of these factors might have on the situation, and how a robotic solution weighs (positively or negatively) against the extra benefits of employing a real human to carry out the tasks, particularly for companion/babysitting jobs, given that there are many jobless youths in our societies these days who would welcome such jobs and could be rather easily trained to carry them out properly (despite what is being mentioned about workforce shortages in these areas).

However, having said and considered all of the above factors, there will always be situations and care scenarios where robots will be found to be cost effective and highly desirable (at least they never lose patience or get bored, unlike some human carers). Human carers are not without limitations, despite their unique positive qualities and interpersonal skills that robots cannot fully match. For robotic solutions to ultimately succeed, a properly qualified human will always need to be present somewhere “in the loop” (for the foreseeable future), e.g., to remotely operate, control and ensure the proper function of a semi-autonomous care robot from a distance (over the Internet).

3.3. Robotics as a Complementary Technology to Self-Care, Home Care and Telehealthcare

The increasing numbers of people with long-term illness and an ageing population are putting an unsustainable demand on the already resource-constrained hospitals and healthcare/social care systems in developed countries. Telehealthcare, home care and self-care have long been encouraged and pushed as strategic policies and directions in these countries, as the way forward for mitigating the increasing demands and burdens on conventional health/care and social care services. The goal is to shift part of the care burden from hospitals/clinics and healthcare professionals to patients and their informal carers, and to help individuals take responsibility of, and better manage, their own health.

3.3.1. Personal Mini Robots for Self-Care

Robots for self-care usually incorporate "robotics as persuasive technology", along the lines of research into "Captology" (the study of computers as persuasive technologies) pioneered at Stanford University, USA, and the work of Michael Siegel on "Persuasive Robotics" (how robots change our minds) [40].

A good example belonging to this class of robots is Autom™, a programmable, sociable, talking mini robot (Figure 2) [21]. Autom™ functions as a personal weight loss coach. It can learn about, and adapt to, its user, providing him/her with tailored advice and motivation, but requires an Internet connection to accomplish its job (as well as a monthly subscription fee to connect to a dedicated online service). Autom™ features a touch screen for a more natural user interaction with the robot's software interface, and can automatically connect to a pedometer (such as Fitbit pedometers) and a bathroom scale [41]. Although Autom™ did well in creating a powerful and long-lasting relationship with its users in the study by Kidd and Breazeal [21], it is still perceived by some other users as a less useful "gimmick", despite the nicety of having a (robot) "face (with blinking eyes)" to communicate with.

Another example of mini robots for self-care is iRobiQ, a small tabletop, multi-purpose educational robot manufactured by a South Korean company. iRobiQ has been programmed by researchers at UniServices at the University of Auckland, New Zealand, and the Electronic and Telecommunications Research Institute in Korea (ETRI), with functions such as blood pressure monitoring, medication management/reminders (to remind user to take the correct medication and dosage at the right times, thus potentially improving medication compliance), and user entertainment (displaying/playing inspirational quotes, music, pictures and videos).

Besides weight loss (Autom™) and hypertension (iRobiQ), future robots of this kind might tackle other health and self-care issues, such as smoking cessation, prevention of sexually-transmitted diseases, *etc*., where the success of current eHealth/mHealth interventions usually stops short of the highly desired changes in consumers' health-related attitudes, convictions and, most importantly, behaviour (the most hard to achieve of all), with results being mostly limited to just changing consumers' knowledge about the subject of the intervention (which has very limited practical value, since consumers still did not quit smoking, eat more healthily, or stop other risky behaviours).

3.3.2. Monitoring, Assistance and Companionship Robots for Home Care and Telehealthcare

Robots bring in the opportunity of addressing the key issue of "integrating health/care and social care" in comprehensive solutions involving both robotics and conventional telehealthcare technologies. The integration of health/care and social care has long been identified as one of the main deficiencies in some existing AAL (Ambient Assisted Living)/telehealthcare provisions and one of the reasons for their lacklustre results in some scenarios [42]. After all, AAL is about enabling and supporting the "independent living of older people", and using a BAN (Body Area Network) for monitoring (and acting on) vital and other clinical signs and symptoms, although extremely useful and important, is just one component of any comprehensive care solution, and not the full solution. Robotics can potentially provide AAL with the (often missing) "social care component", by assisting older people in various activities of daily living and offering them companionship and other much needed services.

Sometimes dubbed "Skype on wheels", Giraff is a telepresence/video conferencing robot manufactured by a Swedish company (Figure 2). Giraff's central communication component is a computer monitor (in portrait orientation) with a built-in webcam. Giraff can be remotely controlled over the Internet to move around a patient's home and interact with home residents via video conferencing. It can be used as a Robot Companion and to pay tele-visits to a patient in his/her home.

The value of Giraff and similar "Skype (or iPad) on wheels" robots is arguable. Similar video conferencing functionality can be achieved using an Internet-enabled living room TV (with a built-in webcam) or even an iPad that can be easily carried by the patient around the home. Many older people live in small homes, often crowded with furniture and other items, with indoor stairs, narrow doors, other unexpected obstacles (cat or dog suddenly moving), *etc*. In such homes, empty spaces/passages for free robot movement are not as controlled or predictable as in a specially designed care home. People might also have concerns about their individual and household privacy [33] with Giraff and similar "home wandering" robots. They might find Skype running on an iPad to be more controllable in terms of what pictures and videos get transmitted from their homes to the outside world.

Furthermore, Egolf [43] argues that "to be a real companion, the robot must be able to fill in for the elder's loss of family and friends, it must be able to relieve the feelings of isolation, and it must be able to send and receive expressions of sympathy and empathy". Such criteria might not be fully achievable using the capabilities of Giraff and similar robots alone.

While telepresence robots might be perceived as cumbersome and less useful/less cost-effective in patients' homes, they might work well in hospital and ICU (Intensive Care Unit) settings, allowing more senior clinicians to be "present" close to their patients' bedside, while they (the clinicians) are physically away/at home after their formal shift hours ("telemedicine on wheels") [44]. The security, privacy and confidentiality of electronic patient data transmissions over the Internet are already regulated by the law and existing healthcare standards; the same rules and standards extend to data transmissions through remote presence robots. Examples of telepresence robots used in hospital/patient bedside settings include RP-VITA [16] and RP-7 [45].

Diagnostic peripherals, such as a stethoscope, can be connected to RP-7. The remote presence robot also has a printer for printing orders and prescriptions and a telephone handset for private communication with the distant clinician. Mendez *et al*. [45] evaluated the feasibility of deploying RP-7 in a distant aboriginal community in Canada. They reported a high degree of satisfaction with the robot and concluded that RP-7 carries the potential for delivering a cost-effective telehealthcare solution to underserviced communities, reducing the need for patients and caregivers' transport to distant referral centres.

In an attempt to address the rather limited health monitoring functionality of Giraff in older people's homes, GiraffPlus was conceived within a three-year project bearing the same name and funded under the European Community's Framework Programme Seven (FP7) of research (2012–2014) [8,30]. GiraffPlus adds a network of environmental and physiological sensors, located in and around the home, as well as (worn) on the body of the older person, to the standard Skype-like Giraff telepresence robot.

However, the real challenge here is not about packing a large array of sensors into a single system (hoping that some of the generated sensor data might prove useful to remote carers and medics at the other receiving end), but rather about making sense of, and acting appropriately and in a timely manner on, the large and often continuous data streams that will eventually arise from such systems, particularly when deployed on a large scale at community or regional levels. Plus, all the original arguments against a "Skype on wheels" still hold true for GiraffPlus. Telepresence using a roving robot ("telemedicine on wheels") is probably more beneficial in a hospital or care home setting, where more controlled spaces need to be navigated and multiple patients need to be "seen" by the remote doctor.

3.3.3. How to Best Combine AAL and Robotics into a Successful Telehealthcare and Home Care Solution

Simply (re)packaging the old Giraff robot with additional wireless (e.g., Bluetooth) sensors scattered around the home (bed mattress pressure/presence sensor, body weighing scale, *etc*.) or worn on the body will not do a lot, without proper and "intelligent" software to reason with the "big data" that are generated, beyond simple threshold-based algorithms/alert triggers (we hope and trust the GiraffPlus team have already addressed this critical issue). In real-world scenarios, we are speaking about hundreds or thousands of older people and their homes being monitored by the same service at same time, so it is indeed big data (or "infoglut"), and there are also serious issues of liability if anything goes wrong, since we are dealing with human lives, as well as issues of service scalability and sustainability. The software has to triangulate and make all those data useful for clinicians (and patients), and has to do so in a timely manner, with minimal false positives and false negatives when detecting incidents or generating alerts and alarms.

Today, one can easily buy very many wireless sensors on the market with their essential software drivers (for connectivity and data collection from the sensor), and connect them to a local hub and remote server, but that (alone) will not make for a useful AAL solution or solve anything serious, clinically speaking. We should be well past this stage in the second decade of the 21st century. The above mentioned "intelligent" software (not to be confused with the essential drivers and networking/"plumbing" software) is not as easy to acquire from the general market or to develop and tune in house. Anyone with the right expertise can do system procurement and plumbing of a sensor network, but not everyone can deliver a useful, safe, reliable and sustainable AAL service (note the difference between a "system" and a "service").

The above thoughts are based on the corresponding author's experience and involvement as Plymouth University lead investigator in eCAALYX (Enhanced Complete Ambient Assisted Living Experiment, 2009–2012), a related European project that was funded under the AAL Programme. In eCAALYX, we tried to address all of the above issues and challenges. The eCAALYX equipment is used for health monitoring, including falls detection, of older and elderly persons with multiple chronic conditions, at home and on the move, and also covers tailored health education and home tele-visits (using home TV). It comprises a BAN (Body Area Network), with relevant sensors (some of which are embedded in a "smart garment" or under-vest worn by the patient, while others are detached, e.g., a Bluetooth digital weigh scale), a special TV set-top box running custom software, a GPS (Global Positioning System)-enabled smartphone running a special eCAALYX app, and a server-side component (software and server hardware).

It is very much hoped that an option will one day be available that integrates eCAALYX with socially assistive robots (operating at home and outdoors), on the way towards the full realisation of a more comprehensive health/social care and daily living solution for senior citizens in the UK, Europe and elsewhere. Consider how one or more robots (e.g., a robotic wheelchair, an eating aid robot and other robots for domestic chores) can be dedicated to a patient 24/7, something that might not be economically feasible to do with nurses and other employed human carers. Moreover, semi-autonomous robots can deliver care in the patients' homes, thus avoiding or reducing the need for hospitalisation with all its extra costs and inconvenience. A wheelchair robot, for example, can help a paraplegic patient live independently, climbing stairs, moving in and out of bed and in and out of chairs, going to the bathroom, *etc*. The wheelchair can open doors and take the patient outside for a "walk" (a built in GPS and special software can provide the patient with "accessible route guidance" [46]). Controlled remotely over the Internet from a local hospital or healthcare centre, the robotic wheelchair can also constantly monitor the patient's vital signs, both when the patient is in the chair and out (wirelessly), and even remind the patient to take their pills. It can understand human speech and gestures, and respond adequately to patient's commands. It has a foldable touch screen attached to its arm offering brain fitness exercises and games to enhance memory and decrease cognitive decline, entertainment (TV, videos, music, virtual tourism, *etc*.) and news, social communication (Facebook, Skype and/or similar tools) to reduce social isolation, online shopping, *etc*. Domotics (home automation) options, e.g., to control home lighting, appliances such as refrigerator or cooker/oven, security locks, *etc*., can further enhance the service [47].

3.4. Some Emerging and Future Robotics Developments and Applications

Soft robots are poised to revolutionise the role of robotics in healthcare and cooperative human assistance. They are made of easily deformable matter that matches the properties of biological tissue and organs, and can adapt their shapes and movements for a broad range of tasks, obstacles and environmental conditions. Potential applications of soft robots include humanoid co-robots for elderly care (soft and lightweight cooperative robots that safely interact with people) and wearable soft robots. The latter can provide a "second skin" for human motor assistance, functioning as artificial muscles to provide physical assistance to people suffering from motor impairments, e.g., following stroke or traumatic brain injury, by cooperating with the body's remaining healthy muscle tissue and compensating for any missing or reduced muscle power. As with natural muscle, these complementary artificial muscles can assist with grasping and other fine motor tasks, and stiffen in order to prevent injury during collisions, absorb impacts, or to catch fast-moving objects [48]. One can even imagine using similar soft, artificial muscle-type activators in the future to enhance left-ventricular myocardial pumping function in patients with failing hearts [49].

The use of robotics technology for humanitarian, disaster relief and related operations is another emerging development worth mentioning. In response to a US DARPA (Defense Advanced Research Projects Agency) robotics challenge call on the subject, robots are currently (at time of writing in 2013) being developed that are capable of functioning as first-responders in natural or man-made disasters to assist victims and help in evacuation operations, e.g., in risky, highly radioactive or bio-contaminated areas.

4. Coda

Robots in health/care and social care are not a single solution or even a single class of solutions, but rather a wide and heterogeneous range of very many options at various levels of maturity, from solutions that might seem gimmicky, impractical or less developed at the moment, to more value-proven options that are well established in everyday mainstream use around the world today. Proper planning, modelling, profiling of end users and market research, testing and evaluation are all essential ingredients in the standard path or "normal cycle" involved in the release of any new product or solution to the market, but only the "test of time" and how users ultimately receive a product after its release to much wider audiences (than those involved in any experimental testing or evaluation procedures) will decide the ultimate fate, success (or lack of it) and levels of adoption of a given solution.

5. Conclusions

In this article, we mainly targeted an audience that has little familiarity with robotics. We examined the state-of-the-art of the emerging field of robotics applications in telemedicine and in the delivery of remote and specialised health and social care. We highlighted the use of robotics in a variety of clinical, home care and self-care scenarios, describing both current (commercially available) and possible future applications of the technology. We tried to offer a balanced viewpoint of robotics efficacy versus cost and limitations. Robotics devices can potentially improve health and healthcare, but large-scale outcome studies or statistically controlled comparison studies are still uncommon as of 2013 and will be much needed over the coming years.

For Web links to research projects, devices and products described in this paper, including additional information and online video clips, the reader is invited to consult [50].

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Conflicts of Interest

The authors declare no conflict of interest. Commercial products and company/brand names mentioned in this paper are trademarks and/or registered trademarks of their respective owners. Reference herein to any specific commercial products, processes or services by trade name, trademark, manufacturer or otherwise does not necessarily constitute or imply its endorsement, recommendation or favouring by the authors. Views and opinions of authors expressed herein shall not be used for advertising or product endorsement purposes.

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