Journal of Assistive Technologies

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Abstract

Purpose – *The purpose of this paper is to provide a review of the use of wearable technologies that focuses on applications that tackle sensory and communication deficits, physical disabilities and alarm and activity monitoring. It is intended to promote the introduction of more wearable approaches to providing assistive technologies because of their benefits in utilisation and aesthetic appeal.*

Design/methodology/approach – *The approach involves a comparison of different types of portable device in order to identify different groups that may be beneficial to different application areas. Recent advances are then considered for each area.*

Findings – *The work demonstrates that the use of wearable AT device is increasing due to improvements in materials, battery power and connected intelligence such as smartphones. They will allow new devices to be introduced that are smaller, lighter and more usable.*

Practical implications – *Utilisation of assistive technologies is likely to improve as wearable devices become the norm across a wide range of applications*

Social implications – *Approaches to improving the Quality of Life of people with disabilities through an extended use of assistive technologies will be enhanced by the increased range of devices available and by their performance.*

Originality/value – *To the best of the authors' knowledge, this is the first review of wearable devices that has focused on the needs of people who have rehabilitation and/or social care needs. Its value lies in encouraging manufacturers and designers to use wearable approaches to solving some of the problems facing vulnerable people.*

Keywords *Social care, Usability, Rehabilitation, Assistive technology, Quality of life, Wearable devices*

Paper type *General review*

1. Introduction

Prevention is seen as perhaps the only sustainable way of managing the health and support needs and expectations in the future as life expectancy increases and many more people will survive serious accidents and illness. This will require a new approach which places greater emphasis on self-care, identification of those at risk, prediction of future problems and the continuous monitoring of vital signs and well-being. Interventions can then be made in a timely manner. So while there will be a big role for population-based initiatives in public health that deal with many of the conditions that can affect everyone – and these include limiting the spread of communicable diseases, improving hygiene to reduce the incidence of food poisoning and reducing the number of accidents in the home and on the roads – there will be increasing emphasis on opportunities to use personalised healthcare that deals with health issues at an individual level.

Received 8 January 2016
Accepted 8 January 2016

Many different types of data need to be collected in order to understand and assess an individual's health and lifestyle; these can be merged to provide an overall index of their well-being (and, perhaps, Quality of Life). However, unless a person lives alone, it is generally not straight forward to record their personal activity data based on parameters measured in the home from use of appliances, movement in rooms, transfer from beds and chairs and opening of doors. Thus, while the Internet of Things advances that connect kitchen appliances and other monitoring devices may yield a rich tapestry of data that can be mined to provide relevant information on household activities, more direct measurements are necessary at an individual level. This may be through devices that people carry and or which are attached to or within their bodies. Such an approach yields highly personal data but may be an unacceptable intrusion and may pose a hacking or digital eavesdropping risk. These security issues can be addressed through appropriate use of technology and through attention to universal design principles that result in aesthetically pleasing hardware.

It follows that any assistive device that helps or enables an individual to perform a task in a simpler, safer or more reliable way also needs to be personal if it is to be always available and optimised for use by one person. This promotes the idea that smart assistive technologies may be useful both in recording activities and in enhancing performance depending on how they are used. Therefore, personalised devices may be useful in many aspects of rehabilitation and in general social care, especially for people who have disabilities.

2. Wearables – pros and cons

The surge of interest in wearable technologies in recent years may be attributed to a number of reasons including the five described below:

1. an increased consumer interest in medical technology, especially with respect to prevention agendas and the need for greater fitness, and levels of activity for improved lifestyle;
2. new interest in personalised and digital healthcare programmes many promoted through apps for smartphones and tablet devices;
3. the availability of nearly universal wireless connectivity through Wi-Fi and mobile networks;
4. recent improvements in electronics and sensing technologies that have resulted in smaller, more light weight and power-efficient devices and dispersed sensors; and
5. efficient and powerful wearable plus portable computing power and software.

Despite these drivers, a number of challenges remain to be overcome before wearable devices replace existing technologies across the spectrum of assisted living technologies. The benefits and the challenges are compared in Table I. Fortunately, rapid progress is being made in meeting and overcoming the obstacles to wholesale adoption.

Table I The benefits and challenges in introducing wearable health technologies

Benefits	*Challenges*	*Comments*
Continuous monitoring of individual's health or well-being status	The power requirements are such that monitoring can only be for finite periods	Body heat/motion can provide power
Empowerment of individuals to control devices and self-manage their conditions	Developing user interfaces that are intuitive so that they can be used by all	Potential users may have cognition issues
Allows remote monitoring of lifestyle and medication adherence	Making them sufficiently robust (and waterproof) to avoid accidental damage	3D printing allows for simpler cases
Offers opportunity to provide direct feedback or intervention to individual	Offering discreet feedback so that information is not accidentally shared	Smartphone apps can be customised
Offers a scaling of measurement capability in the community	Ensuring that they are aesthetically pleasing; easy to sync with smartphones	Wearables as fashion items offer simplicity
Allows measurement of key parameters in new and direct ways	Having new methods of measurement accepted by the medical fraternity	Data needs analysis to improve outcome

3. Wearable devices as a category of assistive technology

The three traditional types of assistive technology are:

1. fixed systems – usually adaptations to the home, including lifts, level access showers, as well as smaller fixtures such as grab rails;
2. portable devices – these are small enough to be moved from room to room and to be carried outside the home; and
3. electronic assistive devices and systems – they use advanced electronics and communications and personalised interfaces to enable people with profound disabilities to control their environment and generate speech or other forms of messaging through various switches.

A fourth group of assistive technology may be described as connected assistive technologies. These devices include radio or other wireless methods that enable data and commands to be shared either locally or, through Wi-Fi and wireless telecoms systems, with remote monitoring stations or carers. The complexity of such systems ranges from electronic record systems that may be used by both community, primary, secondary care, accident and emergency units and paramedics through to individual sensors that offer alerts, alarms or contributions to activity or health dashboards and systems that provide audio or video contact between individuals and their family carers or organisations.

It is apparent that personal healthcare devices need to be close to or within the body of the individual whose health and care are being monitored and/or improved. This ensures that there can be no confusion over whose data are being collected or who is receiving an intervention, but also increases the sensitivity of detection and interaction whilst also improving the signal to noise ratio. This, in turn, reduces the chances of interference and cross-talk which can lead to errors.

Wearable devices are inevitably portable but might also be components in electronic assistive technology systems, especially when used as, or as part of, a user interface for someone who is unable to use standard controls such as switches or keyboards. They are always portable and often connected to other devices. Thus, they are potentially a major new form of assistive technology of relevance to three of the four groups as shown diagrammatically in Figure 1.

It follows that there are many types of devices that should be considered under the general heading of wearable device. These are described with examples and main application areas and comments in Table II.

It may be observed in Table II that the types of wearable device of relevance to social care and rehabilitation are:

- Clothing – into which sensors, actuators and other electronic components may be embedded.

Figure 1 Wearables within the four groups of assistive technologies

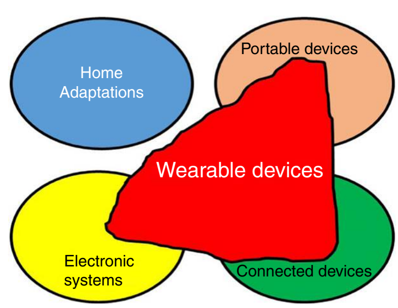


Table II Different types of wearable devices

Wearable	*Example(s)*	*Major areas*	*Comments*
Ingestibles	Pill-cam; smart pills	Medical	Investigations or daily use
Implantables	Pacemaker; artificial pancreas	Medical	Closed loop monitoring and control
Portables	Oxygen canister; TENS machine	Medical	Personal health therapy
Clothing	Vital signs and activity monitoring	Medical/social	Continuous monitoring
Jewellery	Bracelets, brooches, necklaces	Medical/social	Easy to wear and to remove
Attachables	GPS devices, fall detector	Social	Mobile telecare applications
Sensory/speech enhancements	Hearing aids; sight amplifiers; communication devices	Social/ rehabilitation	Most popular forms of assistive technologies
Orthotics	Replacement limbs; exoskeletons	Rehabilitation	Expensive but life-changing

- Jewellery – which provide choice of design in order to be personalised and aesthetically pleasing.
- Attachables – which offer a simple approach to compliance if the design is acceptable to the wearer.
- Sensory/speech enhancements – which enable people who have poor vision, hearing or communication capabilities to engage with others and with their environment.
- Orthotics – which can give people who have lost a limb an opportunity to walk or perform activities of daily living more easily or to appear and feel more complete.

4. Applications for wearables

A large number of wearable devices have already emerged that promise benefits over alternative technologies, especially in the field of continuous monitoring of physiological parameters and adverse incidents including falls and becoming lost. Table III describes the five main application groups for wearable devices. They each have particular requirements that are well suited to having elements that are worn on or about the person. Applications in social care, which includes sensory and physical rehabilitation, and more general well-being are described in more detail below, but may also be grouped in terms of application area in Table III. The first three columns describe user-specific applications while the latter columns refer to technologies that can empower any or all groups and might be deployed most successfully in conjunction with the other devices that are more specific to user groups. The former application areas provide the focus for this paper.

It should be noted that many of these application areas and specific examples of devices have been available for many years but were not seen in the same context as more recent wearable technology innovations. This is partly because they were considered to be items of portable assistive technology and, hence, associated with some form of disability of old age. However, as mobile computing devices (i.e. smartphones) can be used with appropriate software to transform them into connected "cool" devices that are wanted, embraced and appreciated by younger and professional people, it becomes more apparent that issues of usability, portability, adherence, battery life and appearance are becoming more relevant. This may lead to a new surge in interest

Table III General application groups for wearable devices

Overcoming sensory disabilities	*Overcoming physical disabilities*	*Improving monitoring of health, fitness and well-being*	*Providing individual control/ support*	*Computing interfaces and processors*
Low/no vision	Prosthetics	Physiological measurements	Stimulation	Head-up displays
Hearing deficit	Mind control	Activity and sleep tracking	Speech and identification	Data entry devices
Touch/feel	Exoskeletons	Location and other incident alarms or alerts	Switches operated in different ways	Augmented and virtual reality

in more conventional wearable devices and, hopefully, the use of better and more universal designs that make them appropriate for all.

A number of implantable devices will also be relevant to social care and rehabilitation, especially in enhancing sensory performance. These could include bionic eyes and cochlear transplants. However, as they are not readily put on and taken off, we exclude them from our current review of wearable devices.

5. Helping to overcome sensory issues

5.1 Sight enablers/amplifier

People who are registered blind or partially sighted may be guided traditionally by a long white stick or by a dog, but neither is able to identify objects, locations, signs, writing nor people. Bionic eyes and switchable magnification contact lens are already available to support people whose vision has declined through damaged retinas or through age related macular degeneration but it may take several years for such devices to become as acceptable as spectacles for vision improvement. However, for people with poor near vision, reading glasses can now be replaced by augmented reality devices that use a smartphone. For example, using a virtual reality headset of the type shown in Figure 2, and the user may adjust magnification, light levels and contrast in order to maximise the ability to read in comfort.

Braille was liberating for many blind people in that it allowed them to "read" independently; however, using Braille is slow and cumbersome, and because most people lose their sight when they become older, only a small percentage of blind people is able to read braille proficiently. An electronic thimble with tactile sensors and worn on the fingertip can be used to convert braille into words using a smartphone. Indeed, most younger blind people use "speech to text" technology such as Kurzwell while people with dyslexia use apps that take photos as text, scan it and then read it aloud. In a similar manner, ultrasonic sensors can be attached to gloves to provide feedback on solid objects in the environment. Some devices, such as Everonman, use sensors to detect obstacles and alert the wearer to them with vibrations. There are also new lenses with printed electronics light emitting diodes to correct for some disorders such as colour blindness.

However, it is the use of cameras embedded in worn items, or simply worn on the shirt, that offers most potential for overcoming some of the issues faced by blind people. Whilst cameras embedded in gloves can help to identify items on the shelf of a supermarket, those that are fitted into or on glasses can offer much greater opportunities to understand and interact with the environment. This offers the user far greater independence. Some examples are described in Table IV.

Figure 2 Schematic diagram of a simple virtual reality headset

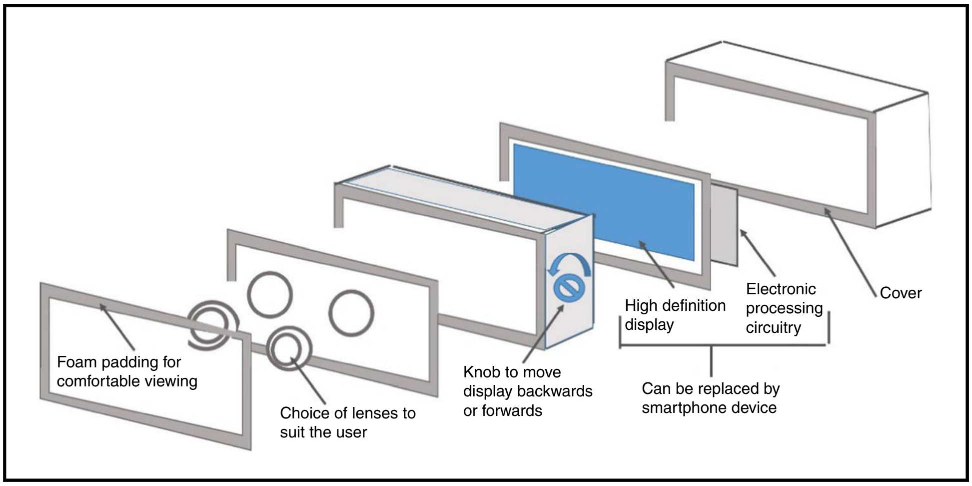


Table IV Examples of camera-based wearable enhanced vision systems

System	*Description*
Orcam smart vision system	Includes a camera linked to a powerful worn computer and a bone-conduction earpiece to provide feedback
BrainPort V100	A 2-part system consisting of glasses with a video camera and a flat receiver that sits against the patient's tongue and transmits "images" via vibrations and tingling
GiveVision high-tec glasses	This can be taught to recognise everything from the entrance and type of shop to bus stops, the number of an approaching bus and any empty seats on it
Oxford smart glasses	This uses cameras and laser to sense objects and process information into bright lights allowing wearer to use their limited vision to understand what's around
eSight	Comprising of a HD camera, a headset, custom prescribed lenses and a controller which processes the images and displays them on small organic-LED displays

5.2 Helping to overcome deafness and hearing loss

Most people experience some hearing issues as they become older. An inability to hear higher frequencies occurs by the early twenties. The effect continues over time for many people who gradually lose the ability to hear the quality of music, for example. For others, the sensitivity to lower frequencies can become so impaired that they are unable to hear speech, especially in the present of other distracting sounds. The earliest hearing aid were portable devices that people had to carry and connect to headphones. The miniaturisation of electronics enabled devices to be worn on and in the ear. Modern digital devices can be tuned to the exact need of the user. However, many owners fail to wear them when needed believing them to be stigmatising and an admission of old age and frailty. Others complain that they do not like what they hear using these aids. Cochlear implants and bone anchored hearing aids also offer considerable benefits. Table V shows some new approaches that are designed to improve usability and sensitivity.

For people who are unable to process sounds presented to their ears, and for whom amplification does not significantly help, there are a number of new wearable approaches that offer alternative ways of transferring data to the individual so that they can use different senses to interpret the sounds. The Versatile Extra-Sensory Transducer (VEST) has an array of 24 vibration motors throughout its surface. Microphones on the VEST pick up the sound around the person, which is then processed and translated into vibrations after filtering out sounds other than speech. Users may recognise words based on the patterns of vibration felt around their torso.

The original Google Glass could be used with smartphone apps to create heads up displays of any measured parameter. The creation of captions is relatively straight forward and, through recognition of an individual's voice, may be used to indicate who is speaking. A neurostimulator with an array of electrodes in a grid at one end may be worn in the mouth and on the tongue as in the BrainPort V100 for blind people. It is connected wirelessly via Bluetooth to an earpiece microphone that captures sound and may be used to convert speech into electrical pulses that are delivered by the stimulator to the tongue which feels tingling or vibration.

Table V New wearable hearing improvement devices

Description	*Technical approach*	*Benefits*
Two directional microphones on spectacles	Rejection of sounds from directions other than where user is looking	Overcomes distractions of background sounds and speakers in a crowded room
Giant magnetostriction effect microphones	Extended frequency range and sensitivity	Improved sound quality, especially for high-frequency speech and for music
EarLens and direct amplification to the eardrum	A laser diode and a tympanic membrane transducer placed deeply in the ear canal	Avoids amplification of extraneous noises whilst providing a flat frequency response
Bone-conduction player	Separate external microphones use Bluetooth to transmit audio signals	Avoids need to insert transducer inside ear canal

5.3 Providing improved sense of touch and feeling

Conditions such as arthritis, stroke and poor circulation can lead to a loss of feeling in the fingers, and also a reduced level of flexibility. The impact of poor tactile sensing and control is that people are unable to recognise hot and cold, to identify objects by touch, and to grip items in ways that are needed to support independent living. Sensor technologies are available that can measure environmental factors, force and texture in accurate and reliable ways that can enable the device to be integrated into smart thimbles or gloves as in Table VI.

As the number of older and disabled people who live alone increases, it is inevitable that social isolation and loneliness will become increasingly important factors that will needed to be addressed by social care commissioners and providers. Family members and third sector organisations may play a major role in engaging these people using third generation telecare systems that offer video communication where distance is an issue, but these technologies fail to offer opportunities for touch, embrace and intimacy that are often an important aspect of physical presence and interaction. It is therefore not surprising that wearable devices have been developed than can, at least partially, fulfil this need. Examples are described in Table VII.

6. Overcoming physical disabilities

6.1 Supporting injured joints and limbs

The most common complication after injuries to the hands and fingers is stiffness. Therapy is an integral part of recovery; rehabilitation can be enhanced by continuous passive motion wearable devices that can move a joint through a range of motion. The fingers of such devices consist of eight rigid 3D printed parts connected by pins. Such devices may be worn for periods increasing from a few minutes to several hours each day until full motion is restored.

Table VI Smart finger and glove devices for improving sense of touch

Device	*Characteristics*
FingerTPS Sensors	Works with signal conditioning wrist assembly to connect up to 6 sensors
The Bicycle Glove	An integrated two-handed glove solution that comprises of 14 sensor arrays placed on the fingers of each hand coupled with a stretchable tactile array
MusicGlove	Has sensors built-in that detect the movement of the fingers – for people recovering from a stroke and other conditions that affect hand movement
Smart powered glove	Has soft actuators made from Kevlar and silicone that work together to close the fingers of the hand under programmable control to optimise rehabilitation

Table VII Wearable clothing items that allow exchange of physical interactions

Garment	*Description and applications*
T-suit	It is covered in a “mesh” of thousands of tiny nodes to translate touch by electrical pulses. Other modules provide temperature sensations
The Squease	Provides warmth and comfort and is beneficial for those who have difficulties processing sensory information, especially people with Autism
Like-A-Hug	It is an inflatable jacket which operates whenever someone “likes” your Facebook posts; a hug can be returned by squeezing the jacket
T-jacket	This applies varying pressure levels to different parts of the body, creating a personalised form of remote physical interaction for children with ADHD
Hug-shirt	This contains embedded sensors that feel the strength of touch, warmth and heart rate of sender, and actuators that recreate the emotion of a hug to the shirt of a distant loved one

6.2 Artificial limbs

The i-limb hand, designed and manufactured by Touch Bionics in Scotland, is the world's first fully articulating, commercially available bionic hand. It allows the wearer to perform many intricate tasks including opening a lock with a small key and slicing bread. It is shown in diagrammatical form in Figure 3.

This bionic hand, given to an Austrian patient, responds to brain signals as a flesh-and-blood hand would. The technique uses muscles and nerves taken from the leg and transplanted to the arm, allowing it to transmit signals from the brain. Alternatively, the latest prosthetic skin is stretchy and warm like real skin, and has tiny sensors that can pick up a variety of environmental cues such as heat, pressure and moisture. It can send sensory information to the brains of amputees to give prosthetic limbs feeling.

There has been similar progress in the development of smart legs, ankles and feet for use by amputees. The springs, pins and pistons used to stabilise the mechanical elements of earlier leg prosthesis have been replaced by force sensors that detect the loading of the foot and ankle, rotation sensors that measure the exact angle of the knee joint and microprocessor-controlled actuators that automatically adjusts leg function dependent on the phase of gait.

6.3 Thought control

US scientists have developed EEG skull-caps and interfaces to control games and car simulators. The Emotiv headset retails for $299 and connects to a laptop through Bluetooth to operate games and apps such as Angry Birds with simple mind controls. In the same way, scientists at a South Korean University and TU Berlin have developed a brain-computer interface for a lower limb exoskeleton used for gait assistance by decoding specific signals from the user's brain. These wearable devices open up a range of opportunities for using brain signals to operate artificial or paralysed limbs without wires or to control a motorised wheelchair (Figure 4).

Figure 3 A diagram showing the features of the i-limb hand from touch bionics

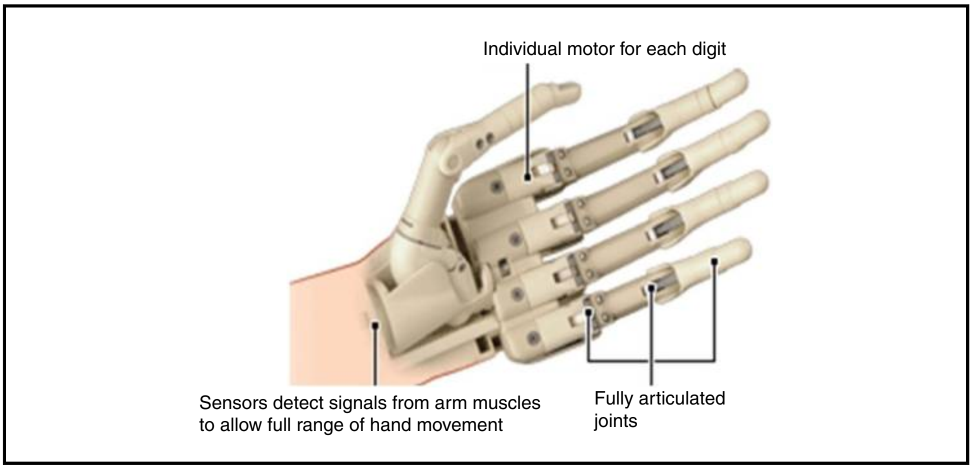
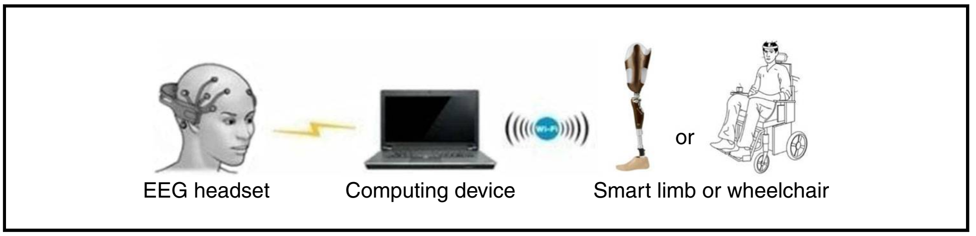


Figure 4 The use of thought control to operate smart assistive mobility devices



6.4 Muscle amplifiers and exoskeletons

People lose body strength as they get older, and also if they are unable to use their muscles for a period of time following illness or injury. In many cases, the power of the muscles cannot recover without significant physiotherapy or exercise. This requires significant resources and is therefore not possible for the majority of people who might benefit. The result is that they are unable to perform many domestic functions including activities of daily living, as well as getting out and about to benefit from exercise, fresh air and company. They could be helped by using wearable support and enhanced movement devices.

There are essentially two different approaches. One uses mechanical motorised exoskeletons or limbs that are attached to the body; these are discussed below. The second approach uses artificial muscles that have the power capability to provide additional strength exactly where needed, whether in the arms or in the legs. Shape alloys have been used previously for this purpose, but suffer from significant instabilities and are not then suitable for applications where accurate and sensitive control of position is required. The latest artificial muscles use polymer fibres that are light weight, versatile and relatively low cost, enabling high power to weight ratios to be produced; they can be activated by a range of external stimuli such as heat, light and electricity so that they could be used directly in wearable support devices, or as components in robotic devices and exoskeletons.

Exoskeletons are essentially mechanical suits that are worn by a person as an outer frame, and which provide and deliver some (or sometimes all) the energy needed for limb movement. They can therefore assist a disabled or frail elderly person to mobilise and/or perform tasks by boosting both their strength and their physical endurance. There are a number of limitations to performance as described in Table VIII.

Nevertheless, exoskeletons have a number of applications both in the military (which lie outside the scope of this paper) and in social care and rehabilitation, including:

- Enabling people to climb stairs both inside and outside their homes, and effectively to replace stair lifts.
- Training stroke or spinal injury patients to relearn how to walk.
- Giving paraplegics the opportunity to move independently without a wheelchairs.
- Supporting nursing staff or carers in transferring disabled people from a bed/chair to a standing position.
- Some of the leading examples of current projects and products are described in Table IX.

Table VIII Technical challenges for exoskeleton suit developments

Challenges	*Description*
Power supply	Batteries and their capacity are a problem for all portable devices and for electrical vehicles. Fuel cells may provide significant opportunities but improvements in batteries such as the solid state Prieto which uses electroplated coating instead of a liquid electrolyte offers an energy density that is orders of magnitude higher than existing technologies and a reduced charging time. The use of aluminium could triple the charge held in lithium-ion devices
Muscle power	Nano-tube technologies could produce stable, easily activated artificial muscles that produce significantly more linear power than moving part mechanical devices
Frame materials	The need for high strength and low weight is common to all support or transport products; new alloys, composites and fibre-based materials are emerging
Actuators	Traditional motors and valves are inefficient or heavy; new integrated approaches needed
Joint flexibility	Reliability may depend on the use of new lubricants and joints that minimise friction through the use of low resistance materials for sockets
Control	Digital control requires user interfaces that are easy to navigate and use especially for those who have physical or sensory limitations; brain control may be required by some

Table IX Exoskeletons relevant to social care and rehabilitation

Name	*Developers*	*Features*
HAL 5	Cyberdyne Inc.	The first cyborg-type wearable robot allows the wearer to lift 10x as much weight as otherwise. It is currently in use in Japanese hospitals, and was given global safety certification in 2013
Ekso	Ekso Bionics	Bionic devices that can be strapped on to the body as wearable robots to enhance the strength, mobility and endurance of paraplegics
ReWalk	ReWalk Robotics	Powered hip and knee motion to enable those with lower limb disabilities, including paraplegia as a result of spinal cord injury (SCI), to perform self-initiated standing, walking and stair climbing or descending
Walking Assist	Honda	Exoskeleton legs and a seat for the wearer which has been optimised to enable a person with lower limb weakness to climb stairs
Rex P	Rexbionics	Offers people with severe mobility issues opportunities to stand and to walk in a hands-free manner
Indego	Parker Hannifin	An electrically powered exoskeleton system for paraplegics to walk confidently with the aid of crutches
MindWalker	European Commission	A mind-controlled exoskeleton for use by a range of physically disabled people
WALL-X	Ghent University	The first exoskeleton that reduces the metabolic requirement to be less than that of normal walking through optimisation of controls
EXARM, X-Arm-2 and SAM	ESA Haptics & Telerobotics	A series of exoskeletons designed to offer robotic teleoperation in an ergonomically efficient manner

7. Improving the monitoring of health, fitness and well-being with wearables

There is considerable interest in the integration of sensors in items of clothing in order to monitor physiological parameters in an ambulatory manner, and also to measure the performance of athletes both during training and in events. However, these are outside the scope of this paper and will be discussed elsewhere.

7.1 Wrist-worn activity trackers

There are many parameters associated with activity that can be measured objectively at the wrist, though the accuracy of some of these may be variable and dependent on the type of activity that the individual is able to perform. Most devices contain two or three axis accelerometers which can provide information on movement levels and rotation which are then converted into other parameters using bespoke algorithms. However, an activity such as knitting may consume few calories but may indicate high levels of activity. The range of options available through different wristbands are discussed in Table X. In all cases, their usability depends not only on the appearance and comfort of the device, but also on the ease of putting it on and taking it off, the secure nature of the band (especially if worn in bed), its water-proofing and the lifetime of the battery between charging. The inclusion of time functionality may be relevant to wearability as a watch may be regarded as a traditional form of jewellery that can be used by men and by woman. Watch-based devices do not, in general, add to the functionality as far as social care and rehabilitation are concerned.

Table X Activity parameters measured by wristbands

Parameter	*Discussion*
Number of steps	Few devices give answers close to the number measured using a pedometer
Distance covered	Can be reasonably accurate if step length is adjusted and if consistent
Calories consumed	Considerable variation but good estimates if weight and height are known so that calories burnt without exercise can also be calculated
Activity level	Relatively straight-forward use of accelerometer to differentiate between normal and high velocity movements
Sleep quality	Restorative sleep can be separated from total sleep time provided that the device is worn in bed, and is not likely to work free
Rest time	The time spent not being active, and the ratio of active-to-rest time may be important for monitoring lifestyle changes needed by people with chronic diseases such as Type 2 diabetes and hypertension

There are dozens of different devices that offer most of the above functions, many through an associated app running on a smartphone. It must be expected that smart wristbands will in the future link with the Internet of Things either directly through a mobile connection or in the home through an Internet of Things gateway that also provides more interaction and control opportunities. There can be little doubt that smart wristbands will continue to be one of the most popular wearable devices available, especially if they can overcome the challenges described above. Ultimately, it may be the appearance of the bands that may determine whether they are wearable, and this may provide genuine opportunities to enhance or personalise the appearance through bracelet design. However, in all cases, the security of devices may need to be enhanced so that the worn component of the system does not become an easy target for hackers.

7.2 Social and smart alarm devices

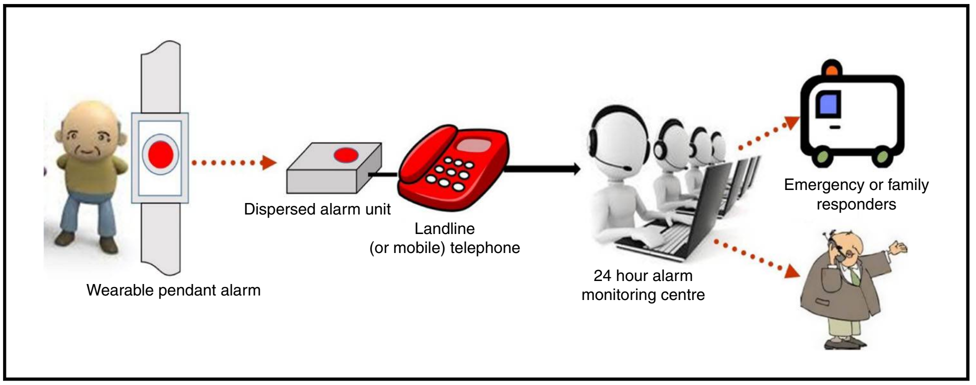
Social alarm or personal emergency response systems have become a vital component in the support of people who live independently in the community, especially if they live alone. There are several million people using such systems in Europe and in North America. Their popularity is likely to spread quickly to other countries as the number of older people increases. These systems are based on four components shown in Figure 5:

1. An alarm trigger – usually a wireless pendant that transmits a short coded message in a regulated narrow frequency band to a telephone interface device with a Class 1 receiver to reject interference.
2. A dispersed alarm unit – a receiver device which interfaces with the landline telephone but which could be integrated into a single mobile unit with a receiver and a SIM card.
3. An alarm monitoring and receiving centre – this will respond quickly to and identify the origins of all calls, enabling appropriate and individual response protocols to be implemented.
4. An emergency response – usually the family of the person wearing the alarm pendant but supplemented by the emergency services where necessary and/or by dedicated responder teams.

The systems of the type shown in Figure 5 are increasingly being used as the basis of telecare services for vulnerable people in their homes and mobile care service (mCare) for when they need support also outside their homes. Alarm telecare uses a range of smart sensors embedded within the home environment and which can detect emerging problems such as:

- extremes of temperature;
- smoke;
- explosive or poisonous gases;
- intruders or bogus callers;

Figure 5 The personal social alarm or emergency response system



- flooding of bathroom or kitchen;
- medication mismanagement or poor adherence;
- nocturnal enuresis or epileptic convulsions; and
- a failure to return to bed or to return home during the night.

Telecare and mCare systems are also increasingly including the use of smart sensor devices that are carried on or attached to the body. These offer more personal and individual approaches to support that can extend to monitoring outside the home in the case of mCare. Some of the alarm opportunities for smart wearable devices are described in Table XI, together with their relevance and application groups.

In each case, the location of the wearable device can be chosen either to maximise its utilisation or to increase its sensitivity. It is often necessary to find a balance between the simplest and most acceptable place to wear a device and the most sensible place to measure a relevant parameter. The advantages and disadvantages of various wearing locations are compared in Table XII with particular reference to fall detection and the avoidance of generating false alarms.

There are many commercial telecare and mCare smart sensors available, most of which are designed for use on the wrist or at any location where it can be located securely. Most offer a range of functions including panic alarm, falls detection and location. In practice, they are able to detect a high percentage of incidents, but are likely also to detect many falls alarms, especially if their detection algorithms have to include the possibility of the device being placed at non-specified locations on the body. They might therefore be useful as impact or shock detectors opening up the possibility of creating a new range of devices that automatically detect that the wearer is unable to get up from the ground, the bed or a sofa.

It may be apparent that wearable devices are already able to compete with many fixed telecare devices in detecting social emergencies. As the availability of mobile networks improve, and as device designs become smaller, lighter and more aesthetically pleasing, mCare will replace landline-based telecare systems.

8. Concluding remarks

The benefits of wearable technology are now clearly established. It is not surprising that applications for wearable devices exist across the spectrum of need from people with sensory

Table XI Emergency situations that can be detected using smart wearable alarm devices

Issue	*User groups*	*Application*
Panic	Anxious people	A simple means of raising an alarm if feeling unwell or at risk
Security	Anxious people	A way of alerting others if worried about security of person or property
Fall	All older or disabled people	Detecting slips, trips and other incidents that leave people unintentionally on the floor, sometimes injured or unconscious
Convulsive seizure	People suffering from epilepsy	Rapidly detecting the rapid jerking movements often associated with grand mal episodes, and alerting carers of incident and location
Becoming lost	Cognitively impaired	People who have a dementia may lose track of time and surroundings leading to them being unable to find their way home at night
Inactivity	All older or disabled people	Lack of movement may be indicative of an adverse incident, such as a fall, or being unwell or immobilised as a result of an accident
Exiting home at night	Cognitively impaired	Up to 40% of dementia sufferers will, often for a few weeks only, walk away home inappropriately dressed in search of a significant place
Entering unsafe area	Frail or visually impaired people	To prevent people with poor eyesight or balance from accessing stairs or other places with hazards that could lead to accidents
Cooking alone	Cognitively impaired or learning disability	To identify attempts to use potentially dangerous cooking appliances that could cause fire, or result in burns or scalds
Bathing alone	Frail or cognitively impaired	Potential for overfilling bath, use of scalding or cold water and suffering a fall getting into or out of the bath or shower

Table XII Comparison of locations for wearable alarm detection devices		
Location	*Advantages*	*Disadvantages*
Waist	Close to the centre of gravity for detecting genuine falls; may be integrated into a belt	Difficult for ladies to wear if they do not have a belt; may be visible and stigmatising
Wrist	A natural location for a watch and other items of jewellery such as a bracelet	Poor location for detecting movement during and after fall; size and design may be unpopular
Around neck	Used in social alarms for decades	Stigmatising and easy to remove and forget
Ankle	Good location for hiding device and for monitoring mobility	Resembles the electronic tags used to monitor the movement of prisoners
Thigh	Can be used to detect attempts to get out of a chair or a bed; easy to conceal	May be uncomfortable to wear; can slide down to the knee
Foot	Sensors can be embedded in socks or hidden in shoes	People change their socks often and may own several different pairs of shoes and slippers
Ear	May be embedded into hearing aid or the frame of spectacles; good for fall detection	Many people need to switch between reading glasses and distance glasses
Head	May be integrated into a cap or a hat	Unlikely to be worn indoors by men

and communication impairments through to older people and those recovering from accidents or surgery and who need rehabilitation. The interest in wearable devices and clothing is currently surging in healthcare and for monitoring of vital signs and well-being. It is likely to result in rapid improvements in the infrastructure for communicating with social care devices, as well as in the availability of platform devices such as wristbands, virtual reality headsets and software. These can be used as the basis of specific developments to support different user groups and for the writing of "apps" that can turn generic devices into bespoke tools that help individuals to live more independently.

Many of the applications described in this paper are standalone, and can be used by potential wearers without being limited by issues of interoperability and compatibility. This is not the case, unfortunately, for those that are designed to support improved quality of life, lifestyle and independence of older people. This group of wearable devices are suitable for being incorporated into a systems approach that may replace some of the expensive social and nursing care currently needed. The selection of these devices should be made following a full assessment of unmet needs, desired outcomes and risks to independence. Solutions are likely to include a range of devices which will increasingly be based on wearable devices within mCare or telecare systems.

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1. Don Kerr, Kerryn Butler-Henderson, Tony SahamaSecurity, Privacy, and Ownership Issues with the Use of Wearable Health Technologies 161-181. [CrossRef]