Intelligent Subcutaneous Body Area Networks

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The area of emerging and futuristic intelligent body-implantable networked devices will begin to materialize as one of the next big themes in future personal computing, offering huge rewards to society if implemented correctly. With this technology potentially beginning to enter the mainstream in the next 5-15 years considerable effort is required to develop legislation, policies, procedures, device and network security, and to convince the general public that this technology is the next logical step in personal computing. This article investigates these systems and analyses the benefits and hurdles the technology is likely to face if we are to realize such systems in our societies of tomorrow.

INTRODUCTION

There exists a long history of medically-prescribed implantable devices to assist the treatment of chronic health conditions; examples include pace makers [1], cochlear and retinal implants [2], insulin pumps [3], and deep brain stimulation implants for relief of Parkinson's disease tremors and seizures [4] to name but a few. There is also a growing trend towards wearable consumer electronics for a myriad of applications, including interactive haptic environments [5], healthcare [6], data communications [7], wearable interfaces [8], and people tracking [9]. Artificial Intelligence (A.I.) continues to make remarkable progress in controlled settings and promises to bring intelligence to everything we interact with [10].

These various domains overlap in the incipient world of subcutaneous consumer electronics devices. Such devices are a range of networked biocompatible consumer electronics devices that users will choose to have implanted into their body to take advantage of new technologies for purposes of convenience, communication, entertainment, fitness, shopping, and security. To date body-implantable electronic devices have been the remit of research centers and fringe enthusiast groups [11], but such technology will enter the mainstream in the nearing future [12], with the vision being one of ubiquitous connectivity – an Internet of Everything (IoE), including humans [13].

This article investigates the strengths, weaknesses, opportunities, and threats for the field of emerging and futuristic intelligent body-implantable devices using a SWOT analysis, with the purpose of identifying, understanding, and evaluating the strategic factors which assist or hinder mainstream realization, and the internal/external forces with which the technology is confronted. Such an analysis is essential for strategic technology planning and inherently considers factors and forces from the aspect of the technology and the users. The article also discusses the role of Artificial Intelligence and machine learning in subcutaneous networks, and aims to emphasize the profile of both the fledgling technology and its assortment of hurdles.

SIGNIFICANT SOCIAL AND TECNOLOGICAL TRENDS

There exists a new generation of makers, hackers, and early-adopters; with this comes increasing acceptance of technological possibilities that the previous generation as a whole would have shunned without consideration. Younger members of society document their lives on the internet for anyone to browse and comment upon, with seemingly scarce regard for security or privacy at times. These individuals may spend a sizable portion of their personal wealth on popular consumer electronics, including smartphones, smartwatches, novelty apps. and gadgets, etc.

There is also a rising social trend of tattooing and body piercing with approximately 10% of those surveyed in England in 2005 having body piercings in places other than the earlobe [14], one in seven Australian adults report having a tattoo [15], and the percentage of U.S. tattooed adults rising from 14% in 2008 to 21% in 2012 [16]. This trend highlights potential acceptance of subcutaneous objects, skin e-tattoos, etc. Tattoos, piercings and implants are all definable as deliberate alterations of the human body and most biohackers (fringe groups who insert various electronic objects on, in, and under the skin) also have multiple tattoos and piercings [17].

Technology is advancing at an ever increasing rate, time-to-market is reducing, and components and systems are becoming smaller and smarter. Future subcutaneous devices will be selected by consumers in the same way that portable electronics are currently chosen, the key difference being their subcutaneous nature. A number of consumer implantable electronic devices already exist, such as the personal identity Verichip (now PositiveID) [18], and rarely a day passes without new smart wearable or future embedded devices making headlines such as brain-computer interfaces (BCI) to operate machines using thought [19], stretchable on-body touch-sensor skin tattoos for mobile computing [20], wearables that utilize bodies as fuel sources [21], contact lenses with controllable magnification [22], and disability-eliminating cyborg systems [23], to name a few.

Artificial Intelligence and machine learning is an old science, but the technology has recently enjoyed a noteworthy jump in sophistication. [24]. Google's artificially intelligent computing system (AlphaGo) made headlines in March 2016 for winning 4 out of 5 games of the 2500 year old Chinese game called "Go" against one of the world's top Go players [25], [26]. This intelligence is spilling into implanted medical devices such as brain-computer interfaces (BCIs) to control artificial limbs [27]. Indeed, with ground-breaking amputated fingertip replacement users can now feel textures [28]. Such advances could allow consumers to be immersed in a virtual reality with multi-sensory perception including realistic touch.

Current medical knowledge understands the body much better than at any time in the past and continues to expand its comprehension of both cell and organ interactions with modern materials and technologies [29]. Bio-compatibility is key interest in developing dental implants, joint replacement, bone cement, skin scaffolding, stints, hip joints, implanted devices, etc. [30]. There are many examples of health-based sensors with high commercial impact; including dental implants to monitor oral health, eating patterns, dietary intake, etc., muscle strain sensors to reduce risk of muscular injury and highlight workout fitness levels, fertility monitors to assist with family planning or abstinence monitoring, internal health monitors to detect illnesses before they develop too far (e.g. bowel cancer) and blood pressure sensors to monitor the "silent killer" in real-time [31]. The last few overlap strongly with medical implantable devices, but many of these sensors may be personal options instead of medically prescribed solutions.

The current wearables market is an indicator for the future implantables market, and the fast developing wearables market already has multitudes of support industries growing around it which provide technology and services (customization, repair, etc.). There are a number of target areas for implantable technologies, some of which are presented in Figure 1. These include automatic gesture control, haptic sensors, and movement detection implants for device control. Other implants may include aural/retinal implants to recover lost hearing/vision or enhance natural senses, as well as embedded communications devices. An embedded microphone and camera would complement these with the potential to replace portable smartphones.

This aforementioned technology is a subset of a larger classification which sees the convergence of consumer technology, robotics, genetics, nanotechnology and artificial intelligence. Such synergies could potentially realize networked bio-technology systems that offer significantly superior intelligence and functionality to the host human; while this is many years away it does suggest the potential in the emerging capabilities of the combined industries.

S.W.O.T. Analysis

A SWOT analysis can be used to study the strengths, weaknesses, opportunities, and threats to analyze the internal and external influencing factors that determine the potential success of this technology. The strengths and weaknesses relate to matters internal to the technology and can be changed through technology revision and tactical R&D; the opportunities and threats are external to the technology, such as public opinion or political/financial climate, and can't easily be changed. It is recognized that a number of the points raised below are not necessarily unique to subcutaneous devices, and many ICT and personal computing devices which boast benefits of portability, efficiency and entertainment value also have issues regarding privacy, personal safety and hacking. However, embedding such technology into human bodies adds numerous new dimensions to the discussion.

A. Technology Strengths

Human-implantable sensor networks exhibit many tangible strengths. There already exists a suitable IEEE standard (IEEE.802.15.6-2012) to which engineers can base development upon [12]. The technology also directly targets multiple markets including entertainment, social networking, personal safety, security, consumerism, communications, healthcare, convenience, and human body upgrading. The technology can enhance future entertainment markets through such aspects as networking with multiple users, environmental emersion and haptic-rich virtual reality environments.

The technology lends itself to futuristic consumerism, employing implanted personal secure e-wallet as the next logical step after smartphone wallets [32]; these help to eliminate financial transaction fraud. Implanted body-area networks could also offer personal safety by smartly tracking location and recording personal interactions with others via sousveillence (Sousveillence is monitoring by way of small portable wearable personal technologies [33]). Kidnappings and human trafficking would also reduce as individuals would have ID tracking implants, with intelligent chemical sensors triggering a distress signal when the individual exhibits extreme levels of stress. It would add new levels of security through unique authentication for building and computer access, removing the need for keys and passwords [34].

A key aspect of this new technology would be in the area of personal electronic communications. The technology could replace mobile phones and other portable computing devices; screens replaced with heads-up displays via contact lenses [35], keyboards on the skin [36], embedded or tattooed microphones [17], surfing the web using only thought [37], etc.

Another fundamental strength is for healthcare and wellbeing. While the distinct area of implantable medical devices is already established these are specifically to treat particular illnesses. Instead, the current growing trend for wearable health and fitness monitors signifies advanced market opportunities for elective implantable health devices. Implanted networks have been considered in academic literature for chronic conditions [38] and long-term general health monitoring [39]. Chronic diseases often benefit from continuous vital-signs monitoring to watch for indicative changes; autonomous intelligent medical implants would be a good way to realize this [40].

Ultimately these implanted networks could enhance the human body to what could accurately be described as super-human ability. Examples include night vision [41] which is currently possible (Figure 2), also super vision, hearing, taste, feel, smell, x-ray vision, mind control of the local environment, artificial intelligence, and mind-reading through sensorfacilitated telepathy are all possibilities. The Internet of Things opens up true opportunities for implanted body networks to realize a new realm of convenience through automation. Neural implants, gesture sensors, haptic sensors, eye gaze sensors, etc. offer real-time remote control of objects, systems, and devices with a wave or a thought. Likewise, belongings such as cars and firearms could be personalized with NFC actuator chips controlling access and operation.

B. Technology Weaknesses

While the technology boasts authentication security, its wireless nature makes it a target for criminal activity including data profiling for nefarious purposes. Likewise, while the technology can reduce robberies, those that do occur are likely to be violent as victims must make transactions in person. Furthermore, kidnappings and human trafficking will require forceful removal of identification/tracking implants.

Because these sensor networks are inserted into the human body there are questions over their safety. Firstly, devices must be implanted correctly to avoid damage to the body (e.g. muscles, nerves, and sinew). Also, there are questions regarding the long term health effects due to electromagnetic radiation from devices. Additionally, it has been shown that medical implants become damaged during radiotherapy [42] and cause tissue heating during MRI scans [43]. Consumer implants may also cause interference with implanted medical devices, ideally legislation shall safeguard against this. However, there will always be individuals and groups who do not use approved implants, or make and insert their own home-made technology [17]; the maker culture and 3D printing already make this a possibility now!

As with all technology, device reliability is an issue. More so if the device is embedded, as if it fails it must be extracted. Similarly, questions as to how the latest hardware upgrades are realized are highly valid, while predatory companies may withhold essential software upgrades until a fee is paid. Embedded A.I. devices with machine learning power could conceivably go rogue, while its quality of decision making is reliant on the programmer's coding skills. If batteries are used will there be long-term battery issues? Would such energy cells leak after a serious personal injury? Currently, chip life is expected to be around 10 years [34], which is not entirely acceptable considering their intended purpose.

Other issues such as how the technology should be implemented and rolled out are of concern. A lack of strategic planning and proliferation of homebrew makers could actually make things worse as amateur devices may not synergistically work within the system as expected. Devices may be subject to software viruses, with conceivably lethal consequences. Also, in very crowded environments where multiple users may physically touch each other (e.g. concerts) will devices interfere or share connectivity they should not? Security settings would address this but experience shows users are poor at ensuring their networked devices are suitably protected [44].

C. Technology Opportunities

Current and developing external factors give human-implantable devices a number of opportunities. The emerging technology-obsessed generation spends their expendable finances on the latest technology trends, often upgrading to the next generation of a device while the previous is perfectly adequate for all their needs. Technology is as much an identity and fashion statement as it is a functional commodity; this rise in personal expression of the individual through technology and fashion is also observed through the increase in tattooing, piercings, and other body art.

Other contemporary social issues could be partially addressed by this technology. Implanted personal computing removes the need to carry so many portable gadgets, reducing the chance of street muggings. Likewise, embedded camera and sound recording technology would further support this, as sousveillence typically reduces extortion [45]. Ubiquitous computing and sensing would be an effective way to reduce terrorist activities and perhaps reduce the impact of successful attacks by aiding recovery and identification of missing persons during disaster scenarios. The same is also true for natural disasters, transport disasters, etc.

Additionally, the health benefits of having sensors permanently monitoring your wellness as opposed to the "snap-shot" health sample at a treatment room would logically result in faster responses to developing conditions and more accurate diagnosis for emergency medical treatment. Medicinal requirements of individuals can be easily and rapidly checked. In a society both obsessed with wellness and immersed in unhealthy lifestyles, a system that is non-invasive to daily living would be warmly received. Furthermore, the opportunity to enjoy upgraded bodily senses (hearing, sight, etc.) is a valued commodity, while the implantable systems would offer genuine personalized experiences for entertainment, education, social networking, and travel.

Technologies such as cloud computing, big data, 5G+, smart cities, biocompatible materials, A.I., energy harvesting, etc. all converge to assist the successful deployment and development of subcutaneous body area networks, ensuring they are usable, useful, and safe. Power considerations for future implanted devices will be supported by emerging energy harvesting solutions; current examples include energy harvesting for autonomous intraocular implants [46] and for heart care devices [47] as depicted in Figure 3. Google's A.I. AlphaGo program highlights the potential for devices and systems to become smarter. Observers of the "Go" competition commented that moves made by the AlphaGo were unlike any a human would ever make [25]; such machine learning and intelligence will take technology to the next level of complexity and automation [48]. This will facilitate smart embedded systems that can look after us, such as current implanted insulin pumps which monitor blood glucose levels and medicate accordingly [3].

Perhaps the most extreme example of how implantable technology could be embraced comes from the small but growing Transhumanist movement (biohackers/grinders) who wish to enhance and repair their bodies indefinitely using advanced technology. These groups see technology not simply as a solution to avoid illness and aid wellness, but as a vehicle to upgrade humans to superhuman semi-cyborg status [11]. Such groups have held international conferences to share their vision and have attracted the attention of such organisations as California Technology Institute and Harvard University. Examples of extra-human capabilities include the power of echo-location (sonar) [49] and the ability to sense electromagnetic fields [50]. While many will view such aspirations as far-fetched scientific fiction, the desire in the modern era to have technology-enhanced bodies is clear.

The above opportunities highlight the potentially large long-term market to satisfy consumer demand, while the increasing acceptance of tattoos/piercings and emerging technologies such as flexible skin e-tattoos [51], stretchable electronics [52] and ink-printable skin antennas [53], all fan the flames of this brave new world.

D. Technology Threats

With the many opportunities come many threats. In fact, this embryonic technology suffers from more threats than most. Even with the new wave of experimenters and hackers, society as a whole is still quite conservative which could lead to a lack of technology adoption. A 2010 survey conducted on attendees at a technology conference reported 23% of 1000 respondents would accept a subcutaneous chip for certain benefits, while 72% would refuse chip implantation under any circumstances [54]. A 2010 trial conducted at the Baja beach club (Barcelona, Spain) offered club members RFID chip implants to make e-payments for bar refreshments and gave access to VIP areas. Despite the obvious benefits the trial highlighted the nervous reception towards the technology [55].

Another major societal threat to implementation exists due to ingrained fears of being chipped and enslaved, and also with identity theft based on the lack of security in current technology. Such problems include concerns over what data is recorded, security against hackers, where data is stored, what data is used for and by whom. [56] highlights the fear that having implantable technology is akin to cattle branding. This subcutaneous technology obviously has much wider applications than mere identification, but the idea of civilized society being reduced to labelling everyone with identifying numbers is fundamentally repellent to some. Of course, the astute reader will note that this is already the case, examples being the social security and national insurance numbers in the U.S. and U.K. respectively.

Fears over the protection of individual human rights and the perceived endless negative function creep are threats to the technology with growing communities of technology users who object to having their data mined by companies for marketing purposes [57]. Such fears reflect a wider trend of increasing distrust of businesses, governments, and organizations which is fueled by publicized high-profile leaks of data abuse such as tapping by the FDA. Employers may begin to utilize bodily sensor networks to facilitate employee monitoring, benchmarking, and performance relate benefits [58].

Likewise, other people's implanted and wearable networks may infringe upon the rights of others in close proximity. Lifelogging using embedded cameras is a growing trend amongst the young, however, some object to being recorded by other people's devices [59]. For instance, in 2012 technology expert Steve Mann was attacked in a French restaurant when an employee took exception to Mann's video-capture eyeglasses [60].

Other barriers to widespread implementation include a strong wearables market negating the attraction of implantables, and inadequate corporate funding to develop technology. Lack of reputable companies developing technology leads to biohacking fringe groups, who already self-mutilate [17] to implant various subcutaneous items [61] such as temperature sensors (Figure 4), as well as fanatical tattooists/piercers who provide implantation services [62], often with few safeguards.

While A.I. and machine learning may open up new opportunities for implanted networks to be smart, fears surrounding machines taking over [63] and recent headline news reports of Google's autonomous car crashing into a public bus [64] casts doubt around the trusting machines to manage high-risk activities. Many fail to realize however that everyday commercial aircraft such as the Boeing 747 [65] utilize "auto-pilot" and "auto-land" computer technology, although to some that may be proof that computers are already too involved.

Further hurdles include the fears of unknown health risks, regardless of the quality of the devices. No data currently exists to evaluate the long term implant risks in humans, however [66] presented evidence of direct correlation between implanted RFID chips and cancer in animals. Furthermore, in 2004 the FDA listed multiple potential health risks associated with the acclaimed VeriChip device [67]. Indeed, wireless devices emitting non ionizing radio frequencies have been categorized as potential carcinogens [68]; hardly something that the average consumer desires to have implanted into their bodies.

Finally, major external factors that could derail success are liberty and religious objections. Most people object strongly to any technology which allows them to effectively be monitored and tracked anywhere in real-time. A number of world religions strictly forbid the practice of tattooing and of cutting the skin, and many Christians would consider subcutaneous identification and e-payment sensors as the impious mark of the beast warned about in eschatological biblical writings.

None of these issues can be overcome easily as many of the objections are difficult to remedy, thus the technology could struggle to enjoy widespread acceptance.

CONCLUSIONS

Body-implantable devices for non-medical purposes are emerging as a hot topic that has the potential to permeate throughout society. This technology has exceptional hurdles to jump that many other emerging technologies do not. This technology could be a great benefit, but also a considerable threat, to future society. If well managed, we could realize a new paradigm in how we work, rest, communicate, play, exercise, age, travel, and shop, with genuine advances in security, entertainment, health, efficiency, commerce, and human body enhancement. This technology will be complemented and enriched by emerging technologies such as Cloud computing, IoT, and NFC. However, if poorly managed or even mismanaged we could face dystopian societies that better reflect a George Orwell novel, with key issues including risks to user health, personal safety, privacy, identity protection, and co-existence with medically prescribed implants. The technology will typically be opposed due to fears surrounding dehumanization, human rights, social privacy, and religious objections.

The role of the Engineering community

To ensure widespread success of the technology it is imperative that a number of recommendations are universally implemented. Such recommendations include the early development of technical regulations which incorporate input and commitment of industrial alliances, governments, academics, clinician, and end users (including the fringe groups), and to develop the technology and standards synergistically with other supporting technologies (IoT, NFC, etc.) to ensure multi-level interoperability. Developing standard clinical procedures for insertion/retrieval of devices is an obvious essential, as are clinical studies to confirm long-term safety.

From a social point of view, recommendations include the carefully managed introduction of the technology in regards to commercial timing, publicity, advertising and use of outcomes from focus groups. Leadership of governments (and subsequent legislation) is similarly essential to guarantee that widespread adoption of technology will not be used for data collection, monitoring, or control of citizens.

To embed such regulations, standards and practices requires time, deliberate orchestration, and cooperation. When there is a desire to realize a new technological advance developers may take shortcuts and deliver the technology before the appropriate checks and balances are in place. [69] voiced such concerns for video surveillance technologies, commenting that "*their use and capabilities are increasing, while policies, procedures, and uses for the information that is visually captured for analysis are still evolving*". To deliver all the strengths that subcutaneous electronics have to offer and to save us from all of its threats, society looks to prominent influential organizations such as the IEEE to develop standards and frameworks to ensure safety and compatibility of devices and systems at every level. We have many challenges ahead to accomplish the reality of implantable systems, but it promises to be a profoundly exciting journey.

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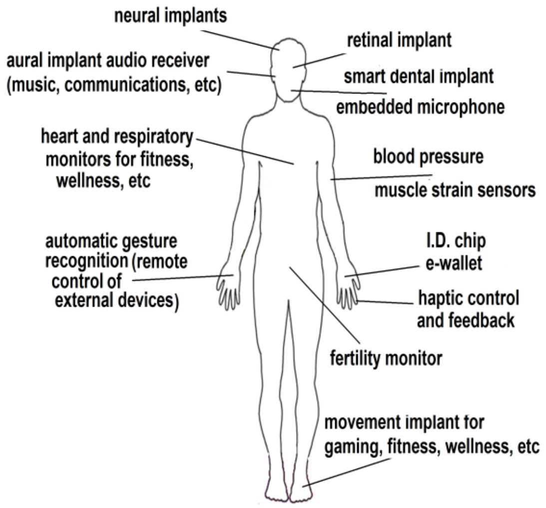

Fig. 1. Target areas for implantable body-area network technologies.

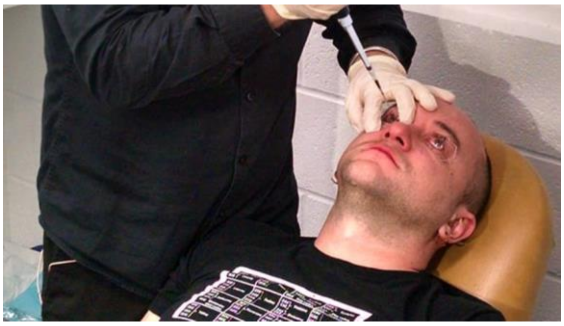

Fig. 2. Night vision eye-drops [41].

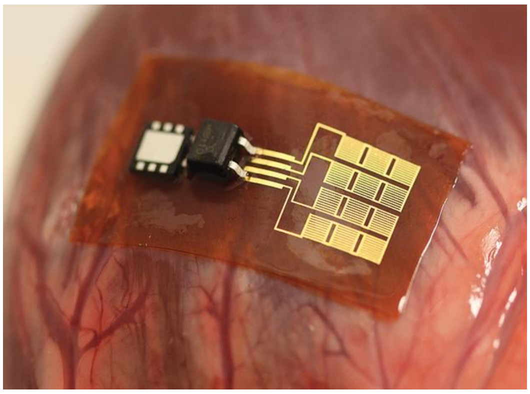

Fig. 3. Implantable energy harvesting Pacemaker [47].

Fig. 4. Self-implanted temperature device [61].