iti Techmedia

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MARKET INTELLIGENCE REPORT
ADVANCED ROBOTICS

An initial study of the market for Advanced Robotics defined as:
"Devices that act largely, or partly, autonomously that interact physically with people or their environment and that are capable of modifying their behaviour based upon sensor data"

CONTENT

EXECUTIVE SUMMARY

This report provides market intelligence into the sector defined by ITI Techmedia as Advanced Robotics. For the purposes of the report the definition of Advanced Robotics is:

> ***"Devices that act largely, or partly, autonomously, that interact physically with people or their environment and that are capable of modifying their behaviour based upon sensor data"***

This Report provides an overview of the Advanced Robotics market, sets out key trends, drivers and inhibitors, reviews the outlook for market development and describes nine market opportunities, one or more of which may form the basis for further ITI Techmedia activities in this area.

Within the next 10-15 years Advanced Robotics is expected to impact increasingly on everyone, both at home and in the workplace. This is a technologically complex emerging market with significant opportunities for the right application.

The Advanced Robotics market is very broad and can be segmented in many different ways. However, a commonly used segmentation is as follows:

- Industrial
- Professional service
- Domestic service
- Security and defence
- Space
- Research and education
- Micro and nano robots.

Within these segments ITI Techmedia believes that service robots – both in the home and professional environment – represent attractive future market opportunities.

Advanced Robotics technologies, systems and products have developed to the point where a number of market applications can already be exploited. Market growth today is occurring mainly in professional service applications, such as medical robots and underwater systems, where there is a clear unmet need and significant expenditure can be justified.

However, a number of issues - such as the cost of robotic systems and unresolved health and safety issues in a co-operative human-machine environment - makes wider application in the home and professional environments challenging. However, as and when such issues are resolved, the opportunities for advanced robotics systems will flourish.

As market opportunities become addressed through technologically novel, economically-viable products, the Advanced Robotics market will witness significant growth in the medium to long term. Indeed, by 2025, the Advanced Robotics market opportunity could be worth over USD50 billion from a base of around USD6 billion in 2006.

The Advanced Robotics market will demand very different capabilities and solutions to that which has driven the development of the dominant robotics market - industrial robots - to date. Given that market growth will be driven by a very different set of solutions, this provides opportunities for the creation of novel business models and technology solutions.

As with any opportunity that offers significant new commercial opportunity, the emergence of aggressive small companies and start-ups can be expected. As such, the Advanced Robotics market could represent a significant new and addressable opportunity for technology businesses in Scotland.

Through the creation of underlying technology platforms, ITI Techmedia could play a role in enabling the development of such businesses. As such, ITI Techmedia has identified nine opportunities that could lead to the creation of technically novel and commercially exciting enabling technology platforms as follows:

- Human-robot co-operative assembly
- Jigless assembly robots for large-scale structures
- Surgical haptics
- Intelligent dextrous catheters
- Intelligent prostheses
- Physiotherapy robots
- Sewer inspection / repair robots
- Nuclear facility inspection robots
- Assisted living / elderly care robots.

Further to this opportunity identification, subsequent analysis has indicated that the following opportunities could form the basis for further ITI Techmedia activity in this area:

- Human-robot co-operative assembly (possibly incorporating aspects of large structure assembly)
- Nuclear facility inspection robots
- Assisted living / elderly care robots.

Prior to progressing activities in this area, ITI Techmedia will seek to engage with ITI Members to validate and confirm those opportunities that should form the basis for its subsequent activities. In addition, ITI Techmedia welcomes R&D programme proposals and expressions of interest in related areas to assist in providing an understanding of the capabilities and commercial interest within Scotland.

1 INTRODUCTION

1.1 Document Purpose

The purpose of this document is to provide a 'snapshot' view of the Advanced Robotics industry in order that the ITI Membership:

- has visibility of the market analysis activities undertaken in this sector by ITI Techmedia;
- can gain access to market information relevant to the sector;
- is provided with some opportunities that ITI Techmedia will explore further to establish whether they offer opportunities for technology innovation that may form the basis of ITI Techmedia research and development programmes in this area.

This document should not be considered as providing a comprehensive analysis of the competitive environment within the robotics industry. Such an analysis is beyond the scope of this document. This report aims to provide an understanding of robotics and its applications. It also aims to give those who wish to act as players in this space an appreciation of the ecosystem and potential scale of this market.

1.2 Document Structure and Content

This document provides market intelligence on the sector defined by ITI Techmedia as Advanced Robotics (see Section 2.1 for the definition of Advanced Robotics). The information captured within the document has been obtained following the principles of market intelligence gathering (otherwise known as foresighting) established by ITI Techmedia.

During the process of developing this market intelligence report, both primary and secondary market data were acquired and collated. Primary data was collected by interviewing experts from academia and commerce, and workshops held. The primary data gathering process was augmented by desk-based research which was used to obtain secondary data from internationally recognised analysts and other sources. Where possible, the source of any data used in this report has been identified.

The document contains the following sections:

- Section 1: Introduction. This Section covers the background, aims and scope of ITI Scotland. It also provides a high-level description of the 'Techmedia' areas of focus. Further background information can be obtained on the website www.ititechmedia.com.
- Section 2: Market Overview. This Section provides a working definition of Advanced Robotics, highlights the main characteristics of the sector and the segmentation of the market. The main trends, drivers and inhibitors are identified
- Section 3: Market Opportunities Assessment. This Section provides an analysis of the top market opportunities identified during the foresighting process. For each opportunity, it includes a description, a market overview, unmet market needs, market drivers and barriers and a timeline
- Section 4: Conclusions and Next Steps. This Section provides the key conclusions of the report together with a summary of the next steps that ITI Techmedia intends to take in the area of Robotics.

1.3 Background: ITI Scotland

1.3.1 Economic Context

A global driver for economic growth is the development and exploitation of technology both for present needs and future requirements. Successful economies are underpinned by a vibrant research base which extends from basic science through to pre-competitive research and development, with a clear focus driven by global market opportunities. Scotland has a reputation for world class research in many fields and already undertakes significant research activity in several areas which have the potential to be strong future market opportunities. In addition to the research base, most developed economies have institutes or organisations that promote knowledge generation and increase commercial exploitation capacity. The establishment of such organisations has had significant economic impact over the long term.

1.3.2 ITI Scotland

ITI Scotland is a commercial organisation focussed on driving sustainable economic growth in Scotland, through ownership of commercially targeted R&D programmes that deliver world-class intellectual assets.

Specialists from ITI Scotland's three divisions - ITI Techmedia, ITI Energy and ITI Life Sciences - identify technologies required to address future global market opportunities, then fund and manage R&D programmes and the subsequent commercial exploitation of new intellectual property (IP). This publicly funded company has an active Membership of interested parties from the business, research, academic and public sectors. Members enjoy exclusive access to market foresighting (such as that contained within this Report), the opportunity to participate in leading-edge technology R&D programmes and networking opportunities brought about by regular meetings of a growing network of like-minded organisations.

The ITIs also interact with each other to identify potential overlap or "white space" market opportunities between ITI Techmedia, ITI Life Sciences and ITI Energy.

The ITIs are a centre or "hub" for:

- identifying, commissioning and diffusing pre-competitive research that is driven by an analysis of emerging markets
- managing intellectual assets to maximise commercial and economic value.

An active Membership is the core of the ITI Scotland model. It is open for Membership to companies and research institutions willing to participate actively in its activities. ITI strategy and operations are actively guided and supported by Members. ITI Scotland seeks Members with a broad global perspective on markets and new technology directions, as well as a local focus, to ensure that propositions will be transferred effectively into the Scottish economy.

1.4 Definition of the Techmedia Sector

ITI Techmedia is centred on the development and creation of commercial opportunities encompassing the communications technologies and digital media sectors. The activities of ITI will bring Scotland's economy to the cutting edge of emerging markets by allowing local companies to access and build upon pre-competitive technology platforms developed by ITI.

The term 'Techmedia' arose out of the need to reflect the market evolution of communications technologies and digital media. The overall trend in the marketplace is one governed by a value chain ranging from content/application generation through delivery to consumption. Content, service provision, delivery channels and enabling and managing technologies can no longer be treated in isolation and ITI Techmedia seeks to operate across the value chain.

The key to identifying opportunities for research and development lies in a process called Market Foresighting which involves detailed market and technology analysis to identify trends, evolving requirements and potential demand for new technology. ITI Techmedia compiles the output of this activity in Market Intelligence Reports which are published to Members. This market foresighting informs our R&D programme identification process.

The Techmedia sector is potentially very broad. Hence a phased approach to market foresighting has been adopted. Previous foresighting has concentrated upon a number of major market areas:

- (Remote) Health
- Commerce and Finance
- Learning and Education
- Communication Services
- Entertainment and Leisure
- Digital Cinema
- Nanotechnology
- Homeland Security
- Ubiquitous Computing.

To date, these foresighting activities have helped ITI Techmedia to identify a number of R&D programmes:

- **Games-Based Learning** - to develop a differentiated creation and authoring platform to simplify the creation of games-based learning content. Completed January 2007
- **Machine-Readable Security Tagging** - to develop an end-to-end system solution, featuring a range of component technologies required to protect brands and combat the growing global threat to products from illegal counterfeit activity. Completed March 2007
- **Ultra-wideband Wireless Communications** - to develop the components, system and network management elements for ultra-wideband wireless technology in consumer markets
- **Condition-based Monitoring** – to apply sensors and networks technology to condition-based monitoring for predictive intervention in animal health
- **Biosensors** - to create a technology platform that will facilitate both diagnosis and treatment of infectious diseases
- **Online Game Development** - To make the games development process more productive through provision of novel technologies that can be integrated into the existing tools and middleware chain
- **Backlighting Using Polymer Optics** - to develop a novel backlight platform for liquid-crystal flat-panel displays to improve viewing quality, reduce weight and improve power efficiency at lower cost
- **Software Integrity Engineering** - to develop novel, user-friendly, code design and development tools that assist in the identification and elimination of critical, high impact, software errors for mainstream applications.

2 MARKET OVERVIEW

Within the next 10-15 years Advanced Robotics is expected to impact increasingly on everyone, both at home and in the workplace. This is a technologically complex emerging market with significant opportunities for the right application.

This section presents an overview of the Advanced Robotics market, its development and the various drivers of that development. As such this section:

- defines the Advanced Robotics market
- identifies the major market segments
- describes the various ecosystems, their characteristics and the major players within them
- reviews forecasts for the evolution of the Advanced Robotics market
- describes major trends, drivers and inhibitors affecting the development of the Advanced Robotics market.

This Section provides a framework for the identification of the specific opportunities described further in Section 3.

2.1 Market Definition

For the purposes of this report, Advanced Robotics is defined as:

> ***"Devices that act largely, or partly, autonomously, that interact physically with people or their environment and that are capable of modifying their behaviour based upon sensor data"***

Specific examples include:

- autonomous vacuum cleaner capable of unsupervised cleaning
- knee surgery device capable of working cooperatively with a surgeon to achieve high precision in knee replacement surgery
- surveillance aircraft capable of autonomously monitoring a target region
- team of miniature vehicles, guided mainly by vision systems, capable of playing football.

The term Advanced Robotics is used to distinguish the market from that of general industrial robots and lo-tech toys, although even here the boundaries are blurred. Industrial robots are, for the purposes of this report, characterised as manipulators working to a set programme within a highly structured industrial environment and capable of only small modification to those programmes (e.g. sensing potential collisions and halting or performing a programme motion with a small offset). As will be shown, new industrial robots are themselves being equipped with the means to alter their programmes significantly to deal with less structured applications.

It is also worth noting that other terms are used for the newly emerging generation of robots which overlap the term Advanced Robotics. In particular the following terms are regularly encountered:

- Service robot: A robot which is designed to perform in the service sector and which would normally have to deal with a lack of structure in the environment and / or task
- Domestic robot: A service robot designed specifically as a consumer product for use in the home or surroundings
- Field robot: A robot designed to operate outdoors or in very unstructured indoor environments
- Cognitive robot: A robot that incorporates functions that are similar to, or based upon, the intelligent behaviour of people or animals.

For the purposes of this report all the above nomenclatures are assumed to be encompassed by the term Advanced Robotics.

This definition is, necessarily, both wide and somewhat fuzzy. Two things emerge from these features of the definition. First, the definition is functionally, rather than market, based. This potentially provides for a very broad range of markets to be covered by the report, all with different characteristics and therefore with different supply chains and market development strategies. Second, the type of devices covered can be functionally and structurally very different (as with an autonomous transport vehicle and a surgical robot). Thus while there may be common technology subsets between groups of robots, no one instance of a technology (possibly no one technology) will be common across all robot application areas. This then, leads to one important observation of Advanced Robotics in terms of technology: rather than being a single technology, Advanced Robotics draws upon and integrates different technologies and disciplines to a greater extent than almost any other current product.

Markets for Advanced Robotics exist in most areas of human activity, although the majority of these are only now starting to emerge. Many have linked the current state of the Advanced Robotics industry to that of the computer industry in the early 1980s, i.e. relatively few, high priced systems largely in the hands of professionals but on the verge of spreading into mass market applications[1] . Several however, including the CEO of Evolution Robotics, Paolo Pijanian[2], point out that unlike the PC, which was essentially a single product, robotics is essentially multi-product and a better analogy is consumer electronics, at least with regard to robotics for the home environment. With this analogy the promise of massive growth is still retained but the question of which area will be the primary growth area is much more difficult to define.

2.2 Market Segmentation

As mentioned above, it is common to consider the market for robotics in terms of industrial robots and service robots. However, when considering the range of potential markets for Advanced Robotics it is necessary to segment the marketplace further. At one extreme, it could be argued that the plethora of potential applications and robotic devices make up a vast array of individual markets but a pragmatic analysis yields seven distinct markets with sufficient similarities to be considered to be a top-level market segmentation. These seven market segments are:

- Industrial[3]
- Professional service
- Domestic service
- Security and defence
- Space
- Research and education
- Micro and nano robots
- Sub-system technologies.

The sub-system technologies category (e.g. speech technologies or localisation algorithms) is strictly not a market segment of advanced robots, as they are not robot products. Rather these are modules or technologies that can be potentially integrated with other systems both within the robotics industry and much further afield. As such they will not be dealt with further within this report but the large potential for technology spin-offs in this area should be borne in mind when considering the wider market potential.

It should also be noted that three of the above segments, Security and Defence Robots, Space Robots, and Research and Education Robots, although discussed within this chapter for the integrity of market segmentation, were excluded from market opportunity assessment due to either extremely high entry barriers or the niche nature of the application.

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[1] For example Bill Gates in the January 2007 issue of *Scientific American*: “A Robot in Every Home”

[2] Presentation at Robot Development Conference & Exposition 2007

[3] For industrial robots only the most recent and advanced machines and applications involving interaction with environments or people are considered in this report

As well as considering the characteristics of the market areas it is instructive also to consider the characteristics of the buyers and users of the systems. For advanced robotic systems the users can be characterised in three classes, namely Governmental, Commercial and Consumer. Figure 1 below highlights the dominant characteristics.

	Governmental	Commercial	Consumer
Sponsorship of R&D	Yes	Unusual Except where high need and limited supply is apparent	No
Product Opportunities	Limited	Moderate but often addressing niche applications	Wide
Functionality (compared to current state of art)	High	Medium to High	Low to Medium
Price	High	Medium to High	Low
Product Volume	Low	Medium	High
Users	Highly trained	Trained	Untrained
Requirements and Standards	Highly specialised	Industry specific Contractually driven	Consumer protection and safety legislation

Figure 1: User characteristics of Advanced Robotics [Source: ITI Techmedia]

Figure 2 below outlines the participation of buyers in the various market segments, and illustrates the key role of government and business in market evolution.

Segment	Governmental	Business	Consumer
Industrial	Minor	**Major**	
Professional Service	**Major**	**Major**	
Domestic Service		Minor	**Major**
Security & Defence	**Major**	Minor	
Space	**Major**		
Research and Education	**Major**	Minor	
Micro/Nano Robotics	**Major**	**Major**	
Sub-system Technologies	**Major**	**Major**	**Major**

Figure 2: Robotics buyers by market segment [Source: ITI Techmedia]

2.2.1 Industrial Robots

Industrial manipulators have been around since the early 1960s but only really took off as a significant application area in the early 1980s with the growing availability of the micro-processor. There are close to a million industrial robots worldwide with the majority in manufacturing engineering plants. The primary market for these robots has been, and still is, automotive assembly, bringing much improved quality and cost savings to the production line. However, this traditional market for industrial robotics has reached maturity and new areas need to be opened up. These areas typically require more of the features of Advanced Robotics to be incorporated within the industrial robot structure.

Although the current market for industrial robots is mature, the incorporation of new technology could provide significant new market opportunities. The International Federation of Robotics estimates that new market opportunities will allow industrial robot sales (currently around 110,000 units per annum) to grow by around 5% per annum over the next 10 years.

In particular there are three functional characteristics which, if incorporated, potentially open up new market areas for industrial robots. These are:

Jigless Assembly

Traditional assembly with industrial robots requires that the items to be joined or assembled are tightly constrained in spatial terms so that all uncertainty relating to the placement of the work-pieces is removed. However, this is both costly (jigging and fixtures in a robot cell typically cost between three and ten times the cost of the robot) and also cannot be applied to very large structures such as aircraft frames. Once the technologies become established, jigless techniques using sensors to determine the actual position of parts, promises a more cost-effective solution for many standard assembly tasks.

Co-operative Working

The standard way of dealing with safety for an industrial robot involves caging off the robot and excluding human workers. However, this prevents joint action where the skill of the worker can be combined with the precision or brute strength of a robot. Examples include the assembly of truck transmission components where the weight of the components make it difficult for a human operative to undertake the task but individual differences make it a difficult task for a robot to undertake automatically. In this example, co-operation between the robot and the human can accomplish the task relatively easily with the robot bearing most of the weight but the human guiding the alignment of the transmission. Such tasks, of which there are many, require new ways of ensuring the safety of the human operatives.

Small Batch Assembly

Within small and medium sized engineering companies there are many tasks which could benefit from the improved quality of robot assembly but where small batch sizes mean that the traditional programming overhead makes the use of a robot uneconomic. New ways of programming a robot using techniques such as ‘teach by example’ and online adaptation could vastly reduce this overhead and open up many new markets for industrial robots.

2.2.2 Professional Service Robots

The professional service robot market segment is, in fact, a collection of many market segments covering industries as diverse as agriculture and healthcare. However, these segments have common features which allow them, at the top level, to be addressed as a single segment. Amongst these similarities are:

- robots tend to be expensive items of capital equipment
- robots have high functionality (and are often leading edge)
- robots tend to be operated by trained personnel
- members of the public are usually restricted from accessing the robots' area of operation
- customers often participate in some aspect of the development of the robot system
- current markets tend to be small with few providers in each niche segment
- safety issues often rely, fully or partially, on the supervisory action of a human operator.

Although these individual markets tend to be exploited by unique suppliers who understand the particular needs of the markets, the similarities of technology and general market approach mean that there is scope for significant technology sharing amongst these markets, even at the current stage of market development.

ITI Techmedia believes that this segment offers significant future growth potential, and some major applications in this segment include:

Medical Robots

The medical market for professional robots can be usefully categorised as Surgical Robots and Professional Physiotherapy Robots. Both categories tend to have the same buyers (i.e. health authorities and hospitals), although the way in which the robots are used and the buying decision tend to differ between the two. In particular there are wide differences in price expectations between surgeon controlled, operating theatre robots and aids for individuals such as intelligent prosthetics and wheelchairs.

Field Robots

Field robots operate in unstructured outdoor environments or highly unstructured indoor ones. This, by definition, is a difficult area in which to develop robots and, in general, robots in this area tend to be rugged and expensive. Many potential markets are starting to be exploited worldwide, such as farming and forestry, with mining being one of the key growth areas, particularly in Canada and Australia.

An important area of field robotics is in hazardous environments, particularly nuclear operations and nuclear decommissioning.

Cleaning Robots

Cleaning robots are generally employed to clean man-made structures or surfaces. Examples include street cleaners, window cleaners, pool cleaners, and pipe and tank cleaners. In general, they are direct replacements of more human-intensive methods of cleaning and the prime driver is cost, although in the case of high rise window cleaning and some tank cleaning there is also an element of safety improvement.

Inspection Robots

Inspection robots are employed in the inspection of civil structures and generally remove the need for human workers to work in confined areas or at heights. The driver is again cost, but in this case there are significant infrastructure savings from removing the need for scaffolding and other safety measures.

Construction/Demolition Robots

Construction has been a target for advanced robot development since the early days. However, while some inroads into construction tasks have been made, the largest use of robots in this category is in demolition work.

Logistics Robots

Logistics robots carry goods or people in an autonomous manner, and applications range from factory logistics systems carrying raw goods and finished product round a factory, through mail and courier robots to large scale cargo handling robots working in docks and railway sidings. An emerging class of logistics robots are mass transportation systems, with free-ranging transport robots starting to replace automated railway systems in certain large facility systems such as theme parks and airports.

Underwater Robots

Subsea robots have been around for a long time and received a major boost when the North Sea oil reserves were being opened up. These traditional Remotely Operated Vehicles (ROVs) were primarily tele-operated systems that allowed operators to perform tasks remotely at depth. More recently Autonomous Underwater Vehicles (AUVs) have been developed that can operate autonomously for long periods of time performing sophisticated missions. Typical applications include pipeline and cable inspection, undersea surveys, fisheries protection and water quality surveys.

Public Relations Robots

Although currently a small market, robots have been utilised in a variety of public relations roles. These primarily have involved guide tasks in museums and galleries and marketing roles at large exhibitions. For guide tasks the ostensible role is to increase the value and facility of the venue to the visitor by providing on-demand information and guiding. However, for both this and the marketing role, a large part of the appeal is the novelty of utilising a robot for these tasks.

Entertainment Robots

In pure number terms this is still a small market but the current spend in this category on a per robot basis is quite large. There are two sub-classes of robot that currently exist in this category. The first is the theme park robot where the prime example is the robot ride that can simulate a roller-coaster and/or flight simulator ride by moving the customer through a series of pre-programmed moves, with or without accompanying visual effects. The second major sub-class is that associated with automated characters within the movie and TV industry, generally referred to as animatronics. However, unlike most other types of robot, the skill set and technologies involved in this area draw heavily on the movie industry traditions rather than on mainstream robotics.

2.2.3 Domestic Service Robots

The domestic service robot market segment consists largely of robotic devices that perform similar tasks as existing products do within the home environment, albeit with some differences and/or added benefits. As such the potential suppliers into this market are often the manufacturers of domestic consumer goods and the supply and service channels are those traditionally used to support such consumer goods. This is a potentially diverse market but there are characteristics which most of the robots sold into this segment tend to have in common. These include:

- The robots are mass market devices with selling prices equivalent to standard domestic appliances
- The robotic functionality is limited to the minimum to provide autonomy for a narrow range of functionality
- The robots are designed to be operated by untrained personnel, often with the minimum of instruction
- Current safety relies upon limiting the amount of damage that could be caused by the robot through limiting the power, weight etc.

The domestic service robot market is the newest of all the Advanced Robotics markets, but some success has already been achieved. This market accounted for some 98% of service robot sales by volume in 2006, although by value the sales represented only approximately 20% of overall service robot sales by end 2006[4].

ITI Techmedia believes that this segment offers significant future growth potential, and some major applications in this segment include:

Domestic Task Robots

This class of domestic robot contains the main consumer product robots. The first mass market application has been the autonomous vacuum cleaner with over 2.5 million units sold to date. Other important applications currently being developed and marketed include home security, window cleaning, pool cleaning and lawn mowing. The lack of safety standards or a general consensus on the safety approach needed for autonomous robots in the home means that all devices currently sold in this sub-class have limited power and are therefore somewhat limited in the speed and/or effectiveness of the tasks they perform. This, and the need to sell at around the price of a standard domestic appliance, is currently a major limitation of robots in this sub-class. No one has yet found the application with sufficient mass appeal to allow high functionality to be delivered at a low price or sufficient "must have" functionality to command a higher selling price.

Leisure Robots

Current leisure robots are in two sub-classes. The first sub-class of leisure robot is the hobbyist robot, and kits aimed at the personal developer of robot systems. Such systems tend to be mobile (wheeled or tracked) platforms but can include walking systems and manipulators. The second sub-class is robot toys which are generally aimed at the children's toy market and tend to be dolls, animals, humanoid robots and cars with various automated functions. However, the distinction between these two sub-classes is not clear, with products such as the Lego Mind Storms system sitting somewhere between the two.

There is a possible third sub-class of domestic leisure robot considered likely to be under development but so far this has not made it to market. This is the personal trainer system aimed to work with people in improving physical fitness. This can be seen as a spin-off from the Professional Physiotherapy Robots as mentioned in Section 2.2.2.

Personal Assistance Robots

Personal assistance robots are designed to provide personal and intimate assistance to home users, particularly the elderly and infirm. Currently these robots tend to be designed for a limited range of tasks such as helping with eating and drinking. A particular type of personal assistance robot is the robotic wheelchair which supplements the standard operation of an electric wheelchair with such features as automatic collision avoidance, making it easier to drive for a person with impaired motor co-ordination.

Much current development work is aimed at providing robot systems to assist the elderly stay in their own homes. They are designed to perform tasks such as general fetch and carry, walking assistance and personal health surveillance.

[4] World Robotics 2007

2.2.4 Security and Defence Robots

Security and defence are currently the two areas of robotics with the largest development spend, with defence robotics being by far the larger[5]. Although aimed at different markets, security and defence have similar functional requirements, similar technologies and tend to be developed and marketed by the same companies for these two markets. The largest current usage of defence robotics is surveillance with air, land and sea-based systems in active duty in such areas as Iraq and Afghanistan. Other uses of defence robotics include bomb and mine disposal as well as work on active weapon systems such as ‘intelligent mines’.

Within the security market the main tasks of current robot systems are, again, civilian bomb disposal and surveillance of buildings and perimeters. Some robot systems have been developed for such tasks as fire fighting and there is active development work aimed at producing robot systems to help in the various stages of search and rescue following large scale disasters.

2.2.5 Space Robots

As with defence robotics, space robots are developed and used only by governmental agencies. Most space robotics work is carried out by NASA and ESA although notable work has been carried out in Russia and some space robotics is developed in Japan and China. There are two main roles for space-based robots. The first is in-orbit operations such as supporting operations on the International Space Station and satellite capture and repair. The second role is planetary exploration involving rovers, free-flyers and moles. This second role is about to receive a major boost due to the support activities necessary for the announced manned Mars missions and the manned return to the Moon announced by both NASA and ESA. Robot landers will be required to undertake early missions to survey proposed landing sites and to undertake initial construction work for habitation stations.

2.2.6 Research and Educational Robots

Advanced research work in universities requires platforms on which development work can be carried out. Sometimes the development of the platform can be included within the scope of the research but often the platform is procured as a tool. Commercially available robotic platforms can generally be classified as mobiles, manipulators or humanoids. Such platforms generally have basic functionality included within the system, or as an option, but are also distinguished by the ease of access (generally of the control software) and the provision of development support tools. There is currently a move within several research communities (the National Science Foundation in the USA and the European Commission within Europe) to select a limited range of preferred platforms that could be used by several large projects and which would then support the comparison and sharing of development results.

At an earlier educational level robotic kits are often used within schools and undergraduate courses to help teach the principles of robotics but also to encourage children and young adults to pursue a career in engineering. Although there are several systems which are specifically designed for education (and which have educational support materials associated with them) many of these systems are similar to the hobbyist robot systems.

2.2.7 Micro and Nano Robots

This is a poorly defined area of robotics generally encompassing small robot devices and robots that handle small scale materials. In the micro robot range, development work is currently under way in several countries, notably USA, Japan and Russia to develop robot systems that are of the order of a few millimetres to tens of millimetres. These are the micro robots. Most of this work is technology push with little application focus and, as well as the miniaturisation of components, tends to focus on the peculiarities of power supplies, communications and control. Some development work is being carried out on small robots aimed at surgery, although those

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[5] The US defence budget for unmanned systems between 2007 and 2013 is USD24.3 billion – Department of Defense Unmanned Systems Roadmap 2007-2032

with the most practical applications tend to be robots in the centimetre range rather than true micro robots.

Micro-robotics also covers systems designed to handle materials on the millimetre scale. Much work has been done on handling systems for wafer fabrication although these tend to be simple micro actuator systems or small versions of simple industrial robots rather than advanced robots. Some development work is being carried out on small multiple robot systems to assist small scale fabrication for prototype and small batch compound electronic devices.

The development work on nano robots is at a very early stage with much of the development concentrating on the fabrication of nano-actuators using materials such as carbon nano-tubes and the synthesis and control of hybrid biological (e.g. bacterial) and engineered systems.

Some very early stage work has been carried out on robotic systems for manipulating nano-components in the manufacture of nano sub-assemblies and systems. Leading work in this area is being done in Michigan State University in the USA and L'Institut des Systèmes Intelligents et de Robotique in Paris. This emerging market tends to use macro scale devices such as electron scanning microscopes as manipulators rather than viewing systems. Such work tends to focus on the tools needed to support such processes and how functions such as force feedback can be incorporated when the actual forces are exceedingly low. Nevertheless such robots will be an important enabler for the emerging market of compound (assembled) nano-structures.

2.3 Characterisation of the Ecosystem

This section details the ecosystem underlying Advanced Robotics markets and details the type of organisation operating within the ecosystem. Although all advanced robotic systems share some common technology components there are also significant differences in how the product gets to market depending upon the application type and area. To facilitate an understanding of this the following points are discussed:

- The technology subsets of an advanced robot
- The generalised market ecosystem
- Specific application differences in the ecosystem.

2.3.1 Technology Subsets of an Advanced Robot

The technology subsets of an advanced robot can be thought of at three levels, i.e.:

- Sub-systems
- Components
- Supporting technologies.

It is the robotic subsystems where the unique attributes of an advanced robot are most visible. At the top level the grouping of the most significant sub-systems of an advanced robot is:

- Mobility
- Manipulation
- Control
- Cognition
- Real world interfaces.

Of course, at this very high-level each of these consists of further sub-categories, which may, or may not, be present depending upon the application. Expanding this classification to the next level yields the following classification of sub-systems:

- Mobility
    - Air Systems
        - Unmanned air vehicles (UAV)
        - Micro-UAVs
        - Aerobots
    - Ground Vehicles
        - Wheeled vehicles
        - Tracked vehicles
        - Walking systems
    - Naval Systems
        - Surface robots
        - Sub-sea robots
- Manipulation
    - Arms
        - Kinematically non-redundant arms ("Standard" manipulators)
        - Kinematically redundant arms ("Dextrous" manipulators)
        - Hyper redundant arms (e.g. snakes)
    - Grippers
        - Universal
            - Human-like
            - Non-human like
        - Application-dependent grippers
- Control
    - Servo control
    - Trajectory control
- Cognition
    - Mapping and localisation
    - Object understanding
    - Scene understanding
    - Planning
    - Language understanding
- Real world Interfaces
    - Human-Robot interfaces
    - Robot–Robot interfaces
    - Network-centric interfaces, e.g. sensor networks

By contrast the components of an advanced robot are, in general terms, the same as those used by many other mechatronic systems. At the top-level these can be classified as:

- Sensors
- Actuators
- Structures
- Power Systems
- Computing
- Communications.

Of course some of these systems, particularly actuators and structures can be very specialised for robot systems. These components can also be further sub-classified with, for instance, sensors being classified into proprioceptive sensors (i.e. those measuring the internal state of the robot) and exteroceptive sensors (those measuring properties of the external world). Going further, exteroceptive sensors, can be further classified into complex sensors (such as cameras and laser scanners) and simple sensors (such as temperature or tilt sensors).

Supporting the sub-systems and components are the technologies of advanced robots. Probably more than any other mechatronic systems, advanced robots rely on a vast array of technologies from mechanical design to cognitive science and from software engineering to ergonomics. It is, however, the engineering of these disparate technologies into a dependable system that determines the technical success of an advanced robot. The glue that puts all these sub-systems, components and technologies together is the discipline of systems engineering.

Figure 3 below illustrates the top-level inter-relationship between the major sub-systems and components in an advanced robot.

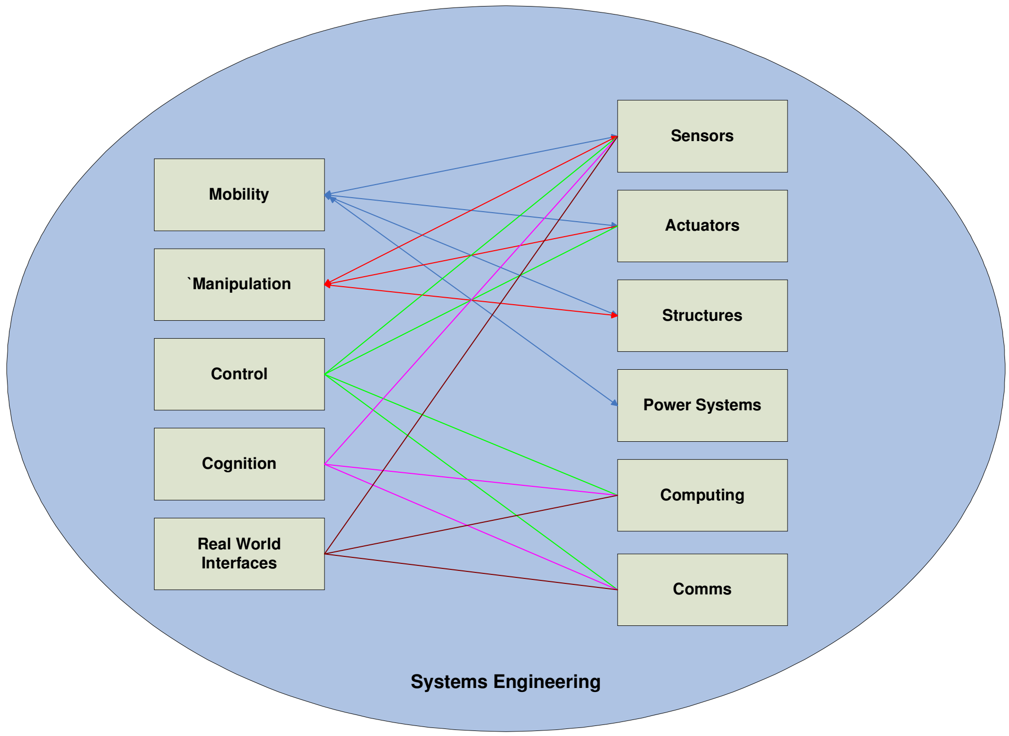

Figure 3: The major sub-systems and components of Advanced Robotics [Source: ITI Techmedia]

2.3.2 Advanced Robotics Market Ecosystem

The Advanced Robotics market is still emerging and currently the role of large organisations is limited, at least in Europe and USA, with most participation by large companies being in defence and industrial robotics. As the domestic market develops it can be expected that large consumer goods manufacturers will become significant players but currently most of the service robot areas are covered by smaller companies or start-ups.

Although differences exist between the major market segments, it is possible to apply a general model to the development and manufacture of advanced robot systems. This is shown in outline form in Figure 4 below.

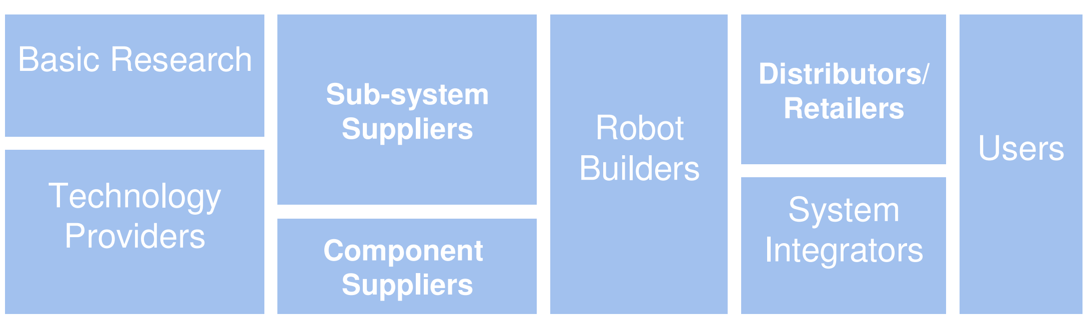

Figure 4: The basic supply chain of Advanced Robotics [Source: ITI Techmedia]

For some market segments, single organisations will cover several parts of this supply chain. Figure 5 below lists the characteristic players for each stage for the Industrial, Professional Service, Domestic Service, and Security and Defence segments. The Space segment mirrors Security and Defence while Research and Education have characteristics of both the Professional and Domestic Service segments, mainly depending upon whether a high or low cost robot is being supplied. The Micro and Nano Robots segment is still at a very early stage and no established supply chain exists yet therefore it is not considered below.

	Industrial	**Professional Service**	**Domestic Service**	**Security and Defence**
Basic Research	Academia	Academia	Academia	Academia
Innovation and Development	Industrial Robot Companies	Small and medium enterprises(SMEs)	SMEs/Consumer Goods Companies	Defence Contractors/SMEs
Component Supply	Specialist Suppliers	Specialist Suppliers	Custom Manufacturers	Specialist Suppliers
Sub-System Supply	Industrial Robot Companies	SMEs	Custom Manufacturers	SMEs/Defence Contractors
Robot Build	Industrial Robot Companies	SMEs	Custom Manufacturers	Defence Prime Contractors
System Build	System Integrators (generally SMEs)	SMEs/Industry Contractors	N/A	Defence Prime Contractors
Distribution	System Integrators	System or Robot Builders	Retailers	System Builders

Figure 5: Characteristic players at each stage in different segments [Source: ITI Techmedia]

As can be seen from Figure 5 above, the Advanced Robotics market will demand very different capabilities and solutions to that which has driven the development of the dominant robotics market - industrial robots - to date. Given that market growth will be driven by a very different set of solutions, this provides opportunities for the creation of novel business models and technology solutions.

Examples of organisations which fill these roles are given in Figure 6 below. No examples of custom manufacturers for domestic robots are given as these are high volume manufacturers where price is the key determinant. For instance, iRobot’s Roomba was moved from undisclosed manufacturers in Taiwan to undisclosed manufacturers in China to maintain the sub USD250 sales price[6]. For Professional Service and Security and Defence no example of end distributor is given as these tend to be the System or Robot Builder.

[6] Taipei Times 27 Sep 2003

	Industrial	Professional Service	Domestic Service	Security and Defence
Basic Research	Fraunhofer IPA; Warwick University	Carnegie Mellon; Heriot Watt University	MIT; Bristol University Robotics Lab	Stanford University; Oxford University
Innovation and Development	Kuka	SME	iRobot/Dyson	Remotec/ iRobot
Component Supply	Panasonic	Schunk; Trimble	SIK; Ninety System Ltd	OC Robotics
Sub-System Supply	ABB	OC Robotics; Evolution Robotics		SeeByte/Qinetiq
Robot Build	Comau	Redzone Robotics; Acrobot Limited		Remotec
System Build	Barr & Paatz	Intuitive Surgical /Atlas Copco		BAe
Distribution	Bradman Lake Group		Amazon	

Figure 6: Examples of characteristic players [Source: ITI Techmedia]

As with any opportunity that offers significant new commercial opportunity, the emergence of aggressive small companies and start-ups can be expected. As such, the Advanced Robotics market could represent a significant new and addressable opportunity for technology businesses in Scotland. Through the creation of underlying technology platforms, ITI Techmedia could play a role in enabling the development of such businesses.

2.3.3 Geographic Variations in Advanced Robotics Markets

The US and European Advanced Robotics markets are similar although there are differences arising from the much higher defence spend on Advanced Robotics in the USA, which is yielding a significant number of SME and start-up companies diversifying into service robot applications. This does not tend to happen in Europe. The relative lack of American industrial robot manufacturers also favours more innovation in Europe in this segment and therefore a greater number of academic organisations pursuing advanced industrial robot applications in Europe than in the USA.

However, the differences between the US and European markets, and the Far Eastern markets are quite significant. The most significant factor is that in both Korea and Japan large companies such as Samsung, Honda, Toshiba and (until recently) Sony, are actively engaged in both the development of Advanced Robotics technology and products. Part of this arises from the national R&D programmes which actively encourage the involvement of large organisations which have established routes to market. Another factor is the greater social acceptance of robotics in Far Eastern cultures and an expectation that leading edge technology companies will be involved in developing these systems. However, there is also a case, particularly with Honda and Toyota, that robots are being used as a general technology development platform rather than with any specific product offering in mind.

The significance to the ecosystem of the involvement of these large companies is that they are generally deeply vertically integrated and can undertake most, if not all, of the roles in-house, from innovation and development to distribution. This is a significantly different model from the one developing in Europe and the USA where much of the robotic development is spread out among a wide range of small companies. In an emerging market it is to be expected that small companies will be more adept at developing and exploiting the niche applications that will first emerge. Whether these niche applications will provide the engines for growth that will enable such firms to tackle the expected mass markets remains to be seen.

2.4 Market Trends, Drivers and Inhibitors

Key trends, drivers and inhibitors impacting on the Advanced Robotics sector are identified below.

Key Trends

- There is an increased spread of automation systems from large factories to smaller operations, driven by the need to maintain competitiveness
- The ageing population in developed nations is leading to high support and maintenance costs and, coupled with shortage of staff, is increasing pressure on care systems
- There is increasing legislative pressure on the protection of the workforce
- The increasing educational level of the population of industrialised nations is leading to increasing difficulties in staffing low status and low paid jobs
- There is an increased usage of minimally invasive surgery supported by systems that help perform these operations efficiently and effectively
- There is an increasing demand for unmanned systems within military operations that remove military personnel from direct confrontation with enemy combatants.

Key Drivers

- The need to improve competitiveness in smaller industries is driving the need for automation systems that can work with smaller batch production processes
- The maintenance of a high quality of life through independent living well into old age is driving the take-up of sophisticated in-home technological aids
- The costs of safety measures to allow manned access to hazardous and confined areas as well as to allow hazardous tasks to be undertaken is improving the comparative affordability of alternative remote techniques
- Need to maintain cost-effective and high quality services, often involving tedious and repetitive tasks, is driving greater uptake of automation systems in service industries
- The need to contain health costs is driving a need to reduce hospital stays and increase throughput which itself is driving the uptake of minimally invasive surgery
- The perceived need to reduce the risk of exposure of armed services personnel to direct engagement with enemy combatants is leading to a large increase in spend upon Advanced Robotics development, which in turn is generating technology that is becoming available for civilian uses.

Key Inhibitors

- The lack of established safety standards guidelines for autonomous systems operating in close proximity to people inhibits the development of systems
- The lack of an established supply industry means that most robot companies have very restricted ability to buy in product, leading to a lack of specialisation in key sub-systems and, consequently, high-cost solutions
- Perception of robots as inhuman and uncaring is a potential inhibitor in the care market
- The inability to identify a key application with mass appeal other than vacuum cleaning is inhibiting the penetration of Advanced Robotics into the home
- The differences between public perception of robots (with both over-expectations and under-expectations fuelled by the media and entertainment industries) and reality inhibits the take-up of robotics either through disappointment in achieved capability or lack of realisation of fitness for task.

2.5 Advanced Robotics Market Outlook

In this section, the evolution of the market for Advanced Robotics is considered. To provide some perspective on this market evolution, it is considered in three parts:

- assessment of long-term market evolution
- progress to date against long-term forecasts
- based upon development to date, forecast of market development to 2010.

Many market assessments forecast strong growth in the Advanced Robotics market over the next 10 to 15 years. This is driven by two main factors

- underlying enabling technologies are now sufficiently developed to allow the development of robust applications
- understanding of the market needs that robotics could meet are now sufficiently robust.

A seminal early forecast is the Japan Robot Association's 1995 forecast shown in Figure 7 below.

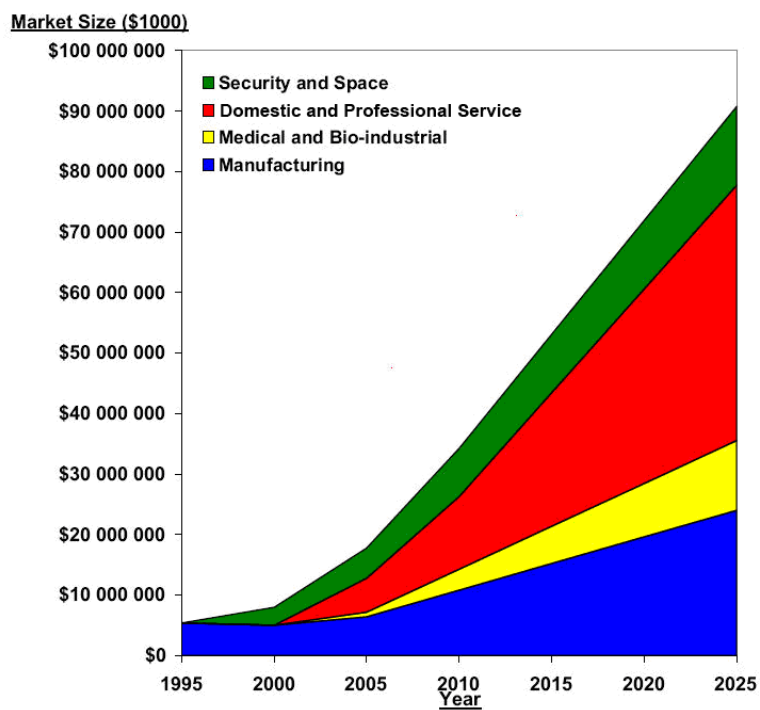

Figure 7: Worldwide robotics market forecast [Source: Japanese Robotics Association]

This forecast predicts strong growth across various market segments, particularly for the domestic and professional service segments. With the manufacturing robotics segment forecast to grow to around USD23 billion by 2025, the implied long-term opportunity in the Advanced Robotics market can be conservatively estimated worth over USD50 billion by 2025. This growth is expected to occur when issues such as the high cost of robotic systems and unresolved health and safety issues in a co-operative human-machine environment are resolved.

As the above forecast is old, the provenance of annual market figures is therefore suspect. However, this forecast is important as it provided clear pointers to the direction of development of the industry, and correctly indicated the growing importance of Advanced Robotics applications over traditional manufacturing applications.

Since the production of this forecast commentators continue to forecast significant growth in the robotics market in the medium to long term although as expected, there is variation in the expected rate of market development:

- global robotics market will grow to USD60 billion by 2025, driven by advanced robotics applications[7]
- global industrial robotics market will grow to USD16.3 billion in 2013[8]
- METI estimates that Japanese demand for robot labour, particularly in the field of nursing-care and public security, will grow to be worth 6.2 trillion yen (USD62 billion) by 2025[9]
- the Japanese robot market will be worth GBP26 billion by 2025[10].

A more recent report "World Robotics 2007" has been published by the International Federation of Robotics which has the benefit of a known provenance, i.e. figures are compiled on the basis of returns from actual robot companies. The statistics in the report are broken down into sufficient detail to allow a view of the developing market. World Robotics 2007 gives an interesting snapshot of the current state of robotics and the expectations of current robot manufacturers of the prospects in the near term. One significant drawback of this approach is that, in an emerging market such as Advanced Robotics, a significant number of new entrants can be expected, some servicing novel, niche application areas, whose views on the future market will not be reflected. It is therefore probable that the figures produced by the IFR are conservative and may well be exceeded.

Advanced Robotics technologies, systems and products have developed to the point where a number of market applications can already be exploited. The value of the service robotics market is forecast to grow from USD5.9 billion in 2006 to USD8.2 billion in 2010 – an average increase of some 10% per annum. Figure 8 below shows the split of value across major service robot market segments in 2006.

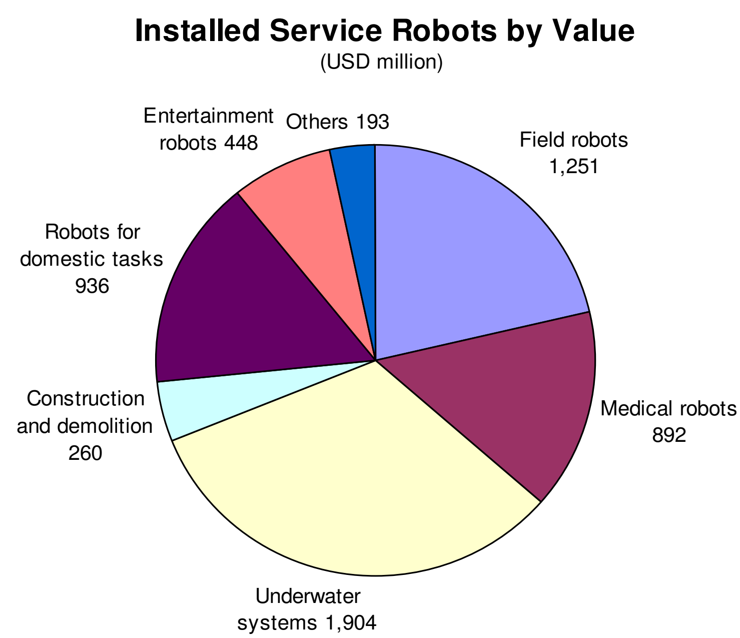

Figure 8: The value of installed service robots at end 2006 [Source: World Robotics 2007]

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7 Professor Minoru Asada, Consumer Electronics Show, 2007

8 www.robopark.org

9 Nagawara Report, METI 2004

10 The Guardian, 30 November 2007

In gross terms the total number of service robots sold in 2006 fell some 12% compared with that of 2005. However, this figure is skewed by a decline in high-volume personal and domestic robot sales. The sales of professional service robots and defence and security robots increased significantly in 2006. A high-level breakdown gives the following growth figures for advanced robots in 2006 compared with 2005.

Domestic service: -12.4%

Professional service[11]: +45.1%

Defence and security: +29.1%

In terms of sales volume Domestic Service Robots at 758,000 represented 98% of the unit sales recorded (with some 530,000 being robot vacuum cleaners). However, in terms of value Domestic Service Robots represented just 20% of total robot installations, showing the much higher value commanded by Professional Service Robots.

Big increases in annual unit sales were noted in most sub-categories of Service Robots showing that this is not a single sub-sector phenomenon. With the levels of growth shown, it is clear that Advanced Robotics systems are addressing a clear unmet need and significant expenditure on robotics systems can be justified. The most significant increases noted in 2006 are shown in Figure 9 below:

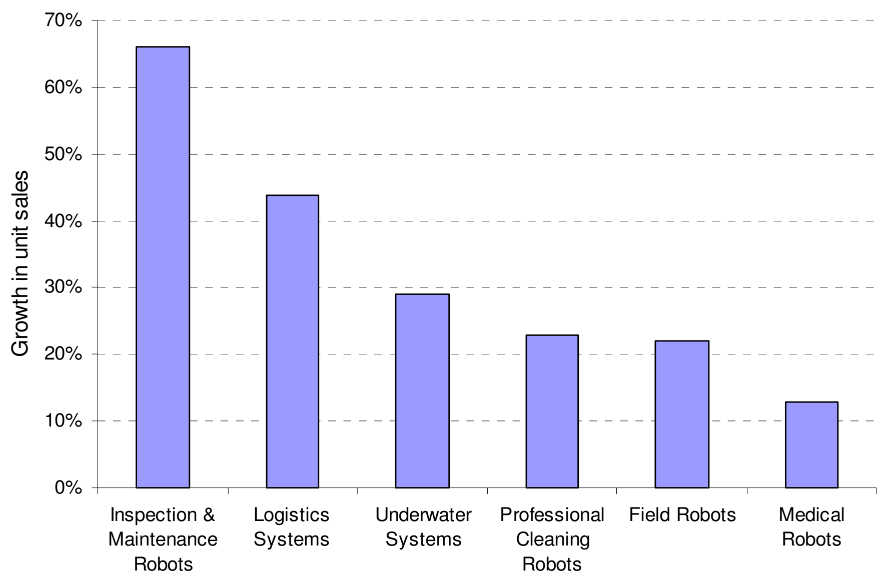

Figure 9: Professional Service Robot sub-category growth highlights 2005 to 2006 [Source: World Robotics 2007]

In 2010, it is forecast[12] that the market for Advanced Robotics will be worth some USD8.2 billion. Professional service robots are expected to dominate the market, as shown below:

Professional Service Robots: USD4.0 billion

Domestic Service Robots: USD2.8 billion

Defence and Security Robots[13]: USD1.4 billion.

[11] World Robotics 2007 does not cover Space Robots, and Education and Training robots are split between Professional and Domestic Robotics. No sales of micro or nano robots have yet been collected.

[12] World Robotics 2007

3 MARKET OPPORTUNITY ASSESSMENT

The objective of the foresighting process is to identify areas of opportunity for the development of technology platforms which address unmet market needs that:

- are unlikely to be satisfactorily addressed by current solutions or approaches in the short term
- have the potential to be addressed in the medium term by new, technology-based developments
- are likely to provide a significant revenue opportunity for market participants in the medium term.

This section describes nine specific market opportunities for Advanced Robotics and the methodology used to derive these opportunities.

3.1 Methodology

The methodology adopted for this report was firstly to undertake research and analysis to identify potential areas of novel application of robotic technologies. Taking as a starting point the seven high level market segments previously described, over 110 individual market areas were identified where robots were currently being used or considered. Within these market areas over 60 emerging applications were identified which have unmet needs. Further study was undertaken to research the markets for these applications.

In parallel with the exercise to determine application areas with unmet needs, several key figures involved with the development of new advanced robot systems were consulted for opinions on the application areas which were likely to display high growth of robotic applications in the coming 3-10 years. The summary output from this consultation yielded the following roughly ordered list:

- Defence/Security
- Medical
- Space
- Automotive Systems
- Environmental monitoring / clean-up
- Toys
- Micro/Nano Assembly
- Agriculture.

The work to this point allowed a high-level prioritisation of market segments to take place. The prioritisation produced is shown below:

- High Priority
  - Professional Service Robots
  - Applications of Industrial Robots in New Markets
- Medium Priority
  - Domestic Service Robots
  - Micro/Nano Robots
- Low Priority
  - Applications of Industrial Robots in Existing Markets
  - Space Robotics
  - Defence and Security Robots
  - Research and Education

[13] There is reason to believe that the defence forecast is significantly understated due to the fact that contributors to the survey represent businesses whose business is wholly or significantly based on robotics. In particular the US prime defence contractors who are participating in the large US defence robotics development programmes are not included. So far an estimated USD18 billion has been spent by US defence agencies on the development and procurement of combat robot systems.

In this prioritisation, Defence and Security Robots were prioritised lower than a straight evaluation of the marketplace would suggest due to the very large current defence R&D spend, particularly in the USA, and the consequent inability for new entrants to make a significant impact with comparatively modestly funded development programmes.

To gain further insight into the possibilities for Advanced Robotics, ITI engaged with international experts with expertise in four different areas of robotic application, namely medical robotics, assisted living, mobile robots and advanced industrial robotics.

In the area of medical robotics seven emerging applications were identified, these being human-centred robots, food assembly robots, snake robots (particularly in medical applications such as working inside MRI scanner and the nuclear industry), swarm robots[14], entertainment robots and medical robots. Two distinct areas in medical robots were highlighted, namely robots for surgery and other medical interventions and robots for assisting those with physical disabilities.

In the area of assisted living the following emerging application areas, in order of market potential were identified: personal and service robots, manufacturing robots, medical and biological robots and security and space robots. In terms of assistive technologies it was noted that future hospital and home-care services will be unable to match future demand and that technological solutions are needed to help meet the projected shortfall in human resources. To maintain the quality of life while living alone the major tasks to be covered are stair climbing and descent, reaching and bending, sitting and walking, general mobility, aids and adaptations and interfacing with domestic appliances. Robots could provide at least a partial solution to these areas. In addition, the overarching importance of safety and user acceptance in this application was emphasised.

In the area of mobile robotics emerging applications in smart guided vehicles, medical robotics, toys, underwater robotics, defence applications and seaport and mine automation were highlighted. Reliability, robustness and safety are seen as major issues in developing realistic applications. In terms of the drivers for future applications of mobile robots these were seen as being either the inaccessibility or undesirability of areas for human operations (such as undersea, the battlefield and space) or where there were clear economic advantages for using automated systems, such as port automation and mining.

In the area of advanced industrial robotics emerging applications in the areas of disassembly (particularly of domestic goods), aerospace assembly, manufacturing in small- and medium-sized enterprises, food assembly and processing and the construction industry were highlighted. Drivers for the uptake of robotics were seen to be demographics, quality of work and, increasingly, sustainability. Robot safety is seen to be a major factor regarding future applications and important technologies are seen to be Web 2.0 (for robots), light-weight, high-strength materials and robust speech recognition. Key areas highlighted for industrial robotic applications were robot assistants that work co-operatively with human workers and robot assistants that can learn tasks in a human-like manner.

Using the data collected from these engagements and complimentary research, the 60+ potential applications were reduced and refined to 25 “long-list” opportunities. These opportunities were then assessed against 10 criteria, with input from an experts workshop held in Edinburgh, to identify most promising opportunities. The assessment criteria (described further in Appendix B) were:

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[14] Swarm robots refer to multi-robot systems that consist of a large number of mostly simple physical robots with collective behaviour emerges from the interactions between the robots and interactions of robots with the environment *(a definition from Wikipedia)*

- Addressable market opportunity
- Potential growth rate
- Competitive advantage
- Industry characteristics
- Number of potential applications
- Timescale
- Technological maturity
- Uniqueness
- IP quality
- IP protectability.

The rest of this section describes in detail the top nine short-listed opportunities as well as giving brief details of the remaining opportunities which were not followed up.

3.2 Description of Top Market Opportunities

The work described above highlighted several areas of potential opportunity with significant scope for innovation, addressing unmet needs and market development. These areas represent an opportunity for the creation of a valuable IP for markets developing within a 3-10 year timescale. The short-listed opportunities are as shown in Figure 10 below:

Opportunity	Summary
Human-robot co-operative assembly	Robot systems working in close proximity with humans in the performance of small batch and artisan activities
Jigless assembly robots for large-scale structures	Robot systems for the assembly of very large scale structures where conventional approaches to robot positioning do not work
Surgical haptics	The provision of force and tactile feedback to surgeons performing minimally invasive surgery with robot systems
Intelligent dextrous catheters	Catheter systems for the delivery of minimally invasive tools and sensors which actively adapts to the shape of the vessel or cavity through which it is inserted, minimising potential tissue damage
Intelligent prostheses	More controllable limb replacement prostheses which have semi-automated capabilities
Physiotherapy robots	Robots to carry out intensive physiotherapy regimes to optimise the recovery of muscle function and tone following injury, illness or operations.
Sewer inspection/repair robots	Robots for inspecting and repairing small bore and hazardous sewers for which access by human operators is difficult and expensive
Nuclear facility inspection robots	The inspection/audit of facilities prior to decommissioning, by small robots equipped with relatively simple sensors to enable accurate planning of the decommissioning process. Also the inspection of the floor of nuclear storage ponds
Assisted living/elderly care robots	Robots to perform a series of critical, but limited tasks, within the home and help a disabled or elderly person to continue to live independently.

Figure 10: Short-listed market opportunities [Source: ITI Techmedia]

Each opportunity is described further in the following sections. For each opportunity the following is provided:

- What is it?
- What application does it enable?
- Market overview
- What are the unmet needs?
- Markets barriers and enablers
- Timescale (market window)
- Key players
- Conclusions.

3.3 Human-robot Co-operative Assembly

What is it?

Human-robot co-operative assembly is a set of technologies and techniques that allow industrial robots to co-operate with human workers in a safe and efficient manner. Traditional industrial robots have high effective inertias, move quickly and (to an outside observer) unpredictably. They also have poor sensing of their environment. This makes them very dangerous and hence direct contact with human workers is prevented by barrier systems avoiding any real physical co-operation in tasks. Co-operative robots, in contrast, will need to share their workspace with human operators and thus need to be of low effective inertia, be able to sense and react to people in their environment and act in an intuitive manner.

What applications does it enable?

Human-robot co-operative assembly is an enabler for automation in a wide range of industries that have, to date, been resistant to change. These include small manufacturers with small batch runs or where the assembly involves artisan operations where traditional programming of robots would not be cost-effective. It also includes the partial automation of tasks involving heavy components that have traditionally been handled with manually controlled lifting gear.

Globalisation is opening up small manufacturers to increasing competition from overseas. Many of these have developed niche markets involving low volume production while at the same time keeping wages contained. However, even these types of operation are becoming susceptible to overseas competition and need to improve competitiveness significantly to retain business and employment within the industrialised nations. This in turn will be assisted by automated systems that can work co-operatively with people in low batch production environment.

Market overview

The market is largely those smaller manufacturing companies that specialise in small batch production or products incorporating specialised manual techniques. An important subset of this overall market is the food assembly market which has been highly resistant to automation due to relatively small batch size, short product life and the handling of difficult, natural products.

Current industrial robot manufacturers do supply this market, but with low penetration and largely for those tasks that are invariant to changes in the product and which can be carried out in isolation behind barriers, e.g. packaging and palletising.

There is a European industry of 228,000 small-medium enterprises (SMEs) that are largely undertaking small batch or craft production. The UK engineering SME market size is GBP34 billion[15]. Additionally, the European food and drink market, of which food assembly is a large component, is worth EUR836 billion per annum. SMEs constitute 99.1% of the companies in this market[16].

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[15] UK Government Annual Business Enquiry 2004

[16] Confederation of Food and Drink Industries of the EEC Data & Trends 2006

What are the unmet needs?

- Cost-effective automation for low batch production
- The capability to learn tasks by example, rather than through direct programming
- The capability to operate safely in a workspace shared by assembly robots and human workers
- The capability to interact with human workers through richer sensor sets, including force sensing, vision and speech understanding.

Market barriers and enablers

- Drivers and enablers
    - Increasingly aggressive foreign competition in manufacturing markets, particularly from the Far East and Eastern Europe
    - The difficulty of recruiting and retaining staff within engineering industries
    - The move, supported by the European Commission Lisbon Agenda, to provide a higher educated workforce is pushing up wage costs and reducing the cost competitiveness of many small enterprises.
- Barriers
    - The temporary supply of cheap labour from Eastern Europe is cushioning many firms against the full impact of increasing wages
    - Lack of effective safety regulations allowing co-operative working between robots and humans could delay practical implementation
    - Specific technology development barriers such as variable stiffness feedback control.

Timescale (market window)

A market exists currently. However, as noted above, this is being somewhat restricted by the lack of agreed safety regulations and the temporary supply of cheap labour from Eastern Europe. Evidence is available that wage expectations of immigrant labour are already rising and current work on safety approaches to advanced robots should yield a greater market opportunity by 2010-12.

Key players

The key players in this market are the industrial robot manufacturers and, in particular, the European based manufacturers who would be the primary mechanism for delivery of systems to the end user. These include ABB, Comau, Kuka and Staubli within Europe and Fanuc, Kawasaki and Motoman in Japan.

Conclusions

The potential market is very large and the technology developments required are achievable, albeit requiring significant progress in several areas. It is also notable that many of the technology developments required to enable effective implementation of multi-purpose service robots are similar to those required for operations within the home and technology developed here could be an important enabler of domestic robots.

3.4 Jigless Assembly for Large-scale Structures

What is it?

The assembly of large structures such as aircraft and ships requires extensive jigs to be designed, built and put in place while the final assembly is being undertaken. Large structures are also resistant to automation due, in part, to the difficulties with working at the same point on both the outside and inside of the structure. Opportunity exists for the development of a set of “jigless” assembly technologies that allow automation as a result of adapting to the position of the structure (rather than forcing the structure into a fixed known position) and accurately determining the relative position of automation components on both sides of the structure through indirect measurement techniques.

A strong lead application is the final assembly of commercial aircraft, a very manual and labour-intensive process that has resisted attempts at automation. This is largely due to the difficulty of applying standard automated assembly techniques, largely developed within the automotive industry, to large structures such as aircraft. Partly this is because precise jigging of aircraft sub-assemblies would be very costly, if not impossible[17], and partly because concepts of absolute accuracy do not apply to structures which naturally deform during the assembly process as well as experiencing significant thermal expansion and contraction due to the normal thermal cycles of the day. The problem of dealing with large structures is exacerbated within the aircraft industry due to the compliant nature of many of the materials used for the components which arise from the need to contain the mass of the aircraft.

For automated assembly to be able to operate successfully on large structures, a system of open loop techniques is required for joining components whereby two physically independent devices are used on each side of the component and locate each other via advanced sensing[18]. On top of this, absolutely accurate specifications may mean little when the structure can move by several millimetres due to thermal variations over the course of a day. What is therefore required is a form of relative accuracy specification which in turn requires that sensors can detect specific data or features in locality of their operation.

What applications does it enable?

The final assembly of commercial aircraft is manpower intensive and is therefore costly. Further, the difficulty of dealing with large structures and of gaining human access to confined areas often means that final assembly is a relatively slow process. Boeing and Airbus are in competition for the global aircraft market and are seeking ways to gain competitive advantage through cost and time reduction in the final assembly process.

Market overview

Final assembly is carried out by the primary aircraft manufacturer. For large aircraft these are primarily Boeing and Airbus. However, other smaller regional manufacturers of aircraft such as Bombardier and Embraer face many of the same problems in the final assembly process.

Both Boeing and Airbus have shown a willingness to invest in production technologies in the past and have even underwritten development costs and assisted new start-ups in the production of machines supporting new techniques.

The UK aerospace market was worth some GBP20 billion in 2006 with R&D investment of over GBP2.5 billion[19]. However, the key target market is the final assembly operations of both Airbus and Boeing. The 20-year global market forecast for new passenger and freighter aircraft between 2006 and 2025 is for some 22,700 aircraft with a total value of USD2.6 trillion[20].

What are the unmet needs?

- Cost effective automation of final wing and fuselage assembly
- The capability to perform “open-loop” joining processes
- The capability to define and utilise relative accuracy assembly specifications.

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[17] Some very large scale riveting machines (e.g. Electro-impact) are used within the aircraft industry for major sub-components but these “close the loop” between the two sides being joined through very large and very stiff mechanical components which are very expensive to build and which are prone to mis-alignment problems as the temperature within the assembly area drifts out of fairly tight tolerances.

[18] This is a specialised subset of jigless manufacturing techniques

[19] UK Trade & Investment

[20] Airbus Global Market Forecast 2006

Market barriers and enablers

- Drivers and enablers
    - Ongoing competition between the two main aircraft manufacturers
    - Increasing safety legislation making the use of manned assembly both more costly and time-consuming.
- Barriers
    - The need to obtain air-worthiness certification for all flight components means that changing design for ease of operation is resisted, making automation more difficult
    - Proving the reliability of the process is a potentially lengthy process.
    - Both Airbus and Boeing have just introduced new aircraft (the A380 and Dreamliner respectively) and therefore any major new process introduced within the next few years would have to be retrofitted to existing assembly lines
    - Specific technology development barriers such as the stable application of high force joining processes utilising open loop systems.

Timescale (market window)

A market exists currently. However, as noted above, both Airbus and Boeing have just introduced new aircraft and so any medium-term implementation would require retrofitting the process to existing production lines, which may be resisted. Waiting for a major new design of aircraft could push the opportunity beyond the 3 to 10-year time window other than for development funding.

Key players

The key players in this market are suppliers to Boeing and Airbus, with suppliers to the regional aircraft manufacturers also being significant players. Major technology specialists in the UK are Airbus and BAE as well as some of the first tier suppliers such as Hyde Group. Nottingham University also has specialist expertise in this area and Leica have experience with accurate measurement systems applied to the aerospace industry.

Conclusions

The potential market is very large and the technology developments required are achievable. The big potential here is to establish a working relationship with one of the two big aircraft manufacturers with a view to obtaining funded development of a product once the credibility is established through undertaking applied R&D. Once developed the technology could be applied to other large structure assembly tasks.

3.5 Surgical Haptics

What is it?

Most current robotic surgical systems involve surgeons actively in the form of tele-operation (e.g. the Da Vinci system[21]). However, to date none of these systems provides the surgeon with a sense of force or feel which he or she would experience performing the operation manually. The aim of surgical haptics is to restore this sense of force and/or touch through measuring the forces and tactile information at the instrument and “playing” them back to the surgeon through the controller.

What applications does it enable?

Tele-operated surgical systems allow surgeons to perform highly accurate minimally invasive operations via very high-quality and high-definition viewing systems combined with the ability to scale down gross motions at the controller to very small fine motions at the instrument.

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[21] http://www.intuitivesurgical.com/index.aspx

However, current systems do not offer any sense of force or tactile feedback, which is an important source of information to surgeons when performing operations manually. Feeling the resistance of tissue can be an important diagnostic tool as can other tactile sensations such as surface texture. Consequently, surgeons often find that they have to perform tasks in tele-operation more slowly and deliberately to compensate for this lack of haptic information. There is also a possible safety implication, although the surgeon can nearly always revert to manual operation in the event of a problem arising.

Market overview

The market for the technology is the general healthcare market with the prime customers in the UK being the National Health Service, private hospitals and teaching hospitals with some interest from insurance companies. Surgeons have a significant role in the decision to purchase new surgical equipment and it is often necessary to work with a lead, or champion, who has an interest in pioneering the technology in order to gain wider acceptance.

The route to market is either through the development of a new surgical robot or by selling on the technology to an existing company in the market.

Worldwide robotically-assisted surgical systems equipment shipment markets are set to have rapid growth. Markets at USD626.5 million in 2007 are anticipated to reach USD1 billion in 2008 and are forecast to go to USD14 billion by 2014[22]. Growth comes because the technology is mature and it works. It took a long time for the markets to evolve, but now the minimally invasive surgeries (MIS) are accurate and less invasive than alternative surgical methods, creating market opportunity.

What are the unmet needs?

- The capability for undertaking robotic minimally invasive surgery with greater efficiency thereby increasing patient throughput and the quality of the surgery
- The capability to provide force and tactile feedback to surgeons performing robotic minimally invasive surgery.

Market barriers and enablers

- Drivers and enablers
    - The need to improve the throughput of patients in minimally invasive surgery
    - Improved utilisation of high value equipment[23].
- Barriers
    - There is a need to find a surgeon sponsor of the technology
    - Medical device approvals can be lengthy and costly to obtain. This particularly applies to a new device entering the market as opposed to a technology upgrade for an existing device.
    - Specific technology development barriers such as providing high fidelity tactile feedback with minimum latency and the provision of very small high fidelity sensors.

Timescale (market window)

A potential market exists currently. This is a known requirement and therefore a time window exists for developing this technology. It is estimated that such technology would need to be available for clinical trials between 2010 and 2012 if it is not to be overtaken by developments carried out by third parties.

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[22] Frost & Sullivan

[23] Each Da Vinci system is sold at an average base cost of USD1.5 million (http://www.reuters.com/article/hotStocksNews/idUSBNG27336320071019)

Key players

One key route to market is through companies already operating in the tele-operated surgical device market. The leading company is Intuitive Surgical in the USA. UK players include Prosurgics and Acrobot. Individual surgeons who already operate robotic surgical devices are important decision-makers in the acquisition process.

Conclusions

The potential market for this technology is significant but probably more so as an enhancement to an existing supplier's offering than through the development of a new device due to the approvals difficulties and the complexity involved in designing and building a high reliability tele-operation system to medical standards. A concern is that haptics as a requirement can be easily captured from any surgeon currently using the existing systems therefore unpublicised development of haptics technology could have been under way or planned, making this a risky proposition.

3.6 Intelligent Dextrous Catheters

What is it?

Catheters often need to be inserted into a body cavity, duct or vessel. Catheters allow the injection or drainage of fluids and also allow the insertion of instruments or sensors for minimally invasive surgery. However, due to the shape of certain vessels or ducts the insertion is not always an easy process and it can be difficult to insert the catheter to the required degree without causing tissue damage. This usually arises because the catheter has to be flexible enough to go easily round bends and yet it has to be stiff enough to allow it to be pushed from the entry position.

The identified opportunity is for a device that will actively follow the path of the vessel while exerting minimal force on the surrounding tissue.

What applications does it enable?

This device allows the easy insertion of a catheter, particularly the long catheters used to support minimally invasive therapy. By allowing rapid insertion with minimal or no tissue damage, the procedure outcome is enhanced and the discomfort to the patient is minimised. The ultimate application would include very small catheters used for the intravenous delivery of surgical tools in heart surgery, etc but this would be a difficult and long term goal. An intermediate prospect consistent with a 3 to 10-year timeframe would be catheters that could be used in the alimentary canal which would require less miniaturisation of both sensors and motors but which would be a transitional step to the production of smaller systems.

Market overview

As with the previous medical opportunities the market for the technology is the general healthcare market with the prime customers in the UK being the National Health Service, private hospitals and teaching hospitals with some interest from insurance companies. Surgeons have a significant role in the decision to purchase new surgery equipment and it is often necessary to work with a lead, or champion, who has an interest in pioneering the technology in order to gain wider acceptance.

The US medical catheter market was worth USD6.8 billion in 2004. The total revenues for this market are expected to reach USD18.6 billion by 2011[24].

[24] Frost & Sullivan

What are the unmet needs?

- Fast and safe insertion of catheters in support of diagnostic and surgical procedures
- The capability to sense the path of least resistance and actively adopt an appropriate pose.

Market barriers and enablers

- Drivers and enablers
    - The need to perform procedures efficiently and safely
    - Patient comfort.
- Barriers
    - There is a need to find a surgeon sponsor of the technology
    - Medical device approvals can be lengthy and costly to obtain
    - Specific technology development barriers such as ultra-small sensors and motor technology.

Timescale (market window)

A potential market exists currently. Exploitation is limited primarily by the development of the technology.

Key players

The key players in this market are Hansen Medical together with a number of university and spin-off companies who are currently offering simple prototype robotic catheters. The National Health Service, private and teaching hospitals will also have an important role in any purchasing decisions.

Conclusions

The potential market is ongoing with scope for technology upgrades and increased scope of coverage. However, the technology is potentially difficult and only initial applications would fit within the ITI timeframe.

3.7 Intelligent Prostheses

What is it?

Existing limb replacement prostheses can be difficult to use and become accustomed to. The identified opportunity is for intelligent arm and leg prostheses which incorporate some automated functions and advanced interfacing, such as direct neural interfaces and learning capability, so that the device can adapt to the user.

What applications does it enable?

Existing prostheses can be difficult to use and become accustomed to. The majority are straightforward mechanical extensions of remaining stumps. Recent developments have seen motorised or robotic limbs which are controlled through movement of the stump, sensing electrical activity at the stump or through a procedure known as targeted sensory reinnervation in which nerves that previously controlled part of the amputated limb are redirected to control a small patch of muscle elsewhere and small movement is then sensed. However, in all cases the patient has to learn how to control the movements of the limb which can be difficult, particularly for fine motor movement.

This particular opportunity has three primary innovations. The first is to provide some automated functions within the prosthesis itself e.g. grasping actions are undertaken with reference to force sensors in the fingers or foot, placement of the prosthesis takes place automatically depending upon body position, gait and speed of motion. Second, the prosthesis should have a direct neural interface to the patient either at the stump or through brain sensing with wireless connection to the prosthesis. Such technology is becoming well developed although it has only been experimentally applied to prosthesis control. Third, the interface should be a learning interface so that not all the adaptation is down to the patient. Preferably the prosthesis needs to be taught the relationship between the command input signal and the desired output.

Market overview

The market is physical rehabilitation, where customers are patients, therapists and insurance companies. Many companies and hospitals produce mechanical prostheses with suppliers often being linked to therapists. Recently several companies have developed robotic prostheses, notably Liberating Technologies Inc and Deka Research & Development Corp both in the USA.

However, with the majority of prostheses still being “dumb” mechanical units and most requiring replacement every 3–4 years, there is a strong downward pressure on costs.

Half limb prostheses (i.e. below the knee or elbow) typically cost somewhere between USD3,000 and USD6,000. Full limb prostheses can cost between USD10,000 and USD35,000. Robotic prostheses are considerably more expensive. Currently there are 1.6 million people in the USA with prosthetic limbs[25]. A prosthetic limb will typically need replacing every 3-4 years. With a mid-price estimate of USD10,000 this yields a potential current market size of USD4 billion in the USA alone.

What are the unmet needs?

- An easy to use and learn prosthesis
- The capability to recognise certain tasks and complete fine motor tasks autonomously
- The capability to adapt motor movements to recognised patterns of neural input.

Market barriers and enablers

- Drivers and enablers
    - Quality of life issues for amputees.
- Barriers
    - The major barrier is one of cost with simple prostheses being available at much lower costs than that at which a robotic arm could be sold
    - There are specific technology barriers, particularly relating to power consumption, energy efficiency and lightweight drives.

Timescale (market window)

A potential market exists currently. Exploitation is limited primarily by the development of the technology. However, the technology barriers are significant and it is to be anticipated that product with significant additional benefits would not be ready for the market in less than eight to 10 years.

Key players

The key players in this market are the many small companies and organisations producing prostheses together with the much smaller number of robotic prostheses manufacturers. Prostheses manufactures include Ossur, Chas A Blatchford & Sons and Ortho Europe. Robotic prostheses manufacturers include Prosthetic Robotics and Liberating Technologies Inc. The US army also has a key technology role in this area being a sponsor and developer of technologies for rehabilitation of injured soldiers.

Conclusions

This is a significant market with potential for entry with a disruptive technology. However, the existing market has strong price constraints and the technology would need marketing directly to end users to achieve significant market penetration.

[25] In Motion (A publication of the Amputation Coalition of America) Volume 15, Issue 5 2005

One additional benefit is that the core neural interface and learning technology, once developed, could be spun out into many other applications such as computing and gaming interfaces. An alternative strategy would be to develop this core technology along with the adaptive control and license this to existing manufacturers.

3.8 Physiotherapy Robots

What is it?

This is an opportunity for robots to carry out intensive physiotherapy routines to a pattern specified by a physiotherapist but operated by the patient. The robots would also recognise changes in muscle performance and tone, and adapt or optimise the routines appropriately.

What applications does it enable?

Following a stroke or operation it is often necessary to perform regular physiotherapy exercises. Recovery is often enhanced if these exercises are carried out regularly and with increased intensity as muscle tone and function is recovered. However, the availability of therapist time is limited and often patients are given lower frequency therapy sessions than optimal or are given exercises to perform on their own. Patients may lack motivation or knowledge on progress and hence fail to perform adequately. In both cases recovery is slower and, in some cases, there is failure to regain full muscle function and tone. A physiotherapy robot would allow optimum frequency and intensity of therapy sessions, provide the motivation for patients to undertake the therapy and adapt dynamically to the needs of the patient. A reporting function would also allow summary reports to be compiled and submitted to the physiotherapist for review.

Market overview

There are 150,000 new stroke cases per year in the UK alone and the direct care costs National Health Service some GBP2.8 billion per year.

In the UK, physiotherapy provision is largely through the National Health Service with a smaller number of private practitioners and some overlap with other private professions such as osteopaths. In 2005, there were 1,200 physiotherapy posts filled in England but it was the specialism with the highest number of vacancies within the NHS. In October 2006, it was reported that there were 28,000 patients on the waiting list for physiotherapy in Scotland alone.

What are the unmet needs?

- Rapid and ongoing access to physiotherapy
- Home-based rehabilitation systems with remote monitoring
- Cost-effective personalised therapy routines
- Dynamically adjusted intensity of routines for optimised recovery as compared with self-administered exercises.

Market barriers and enablers

- Drivers and enablers
    - More effective and efficient use of limited physiotherapist time
    - Reduced NHS long-term costs through the effective recovery of patients
    - Governmental push to develop more home-based healthcare solutions.
- Barriers
    - Potential cost issues within the NHS
    - Lack of effective safety regulations allowing co-operative working between robots and humans could delay practical implementation
    - Specific technology development barriers such as safe control and development techniques.

Timescale (market window)

A potential market exists currently. Exploitation is limited primarily by the development of the technology. With appropriate development funding, products such as these could reach the market within five to six years.

Key players

There are no identified existing key players in this market. The competition would come from the existing physiotherapists. There could be some future overlap with manufacturers of sports trainers.

Conclusions

There is a significant potential market although the accessible market in the UK is largely determined by the ability to sell this system to the NHS. If successful, the professional and domestic sports training markets would be natural developments for the technology.

3.9 Sewer Inspection/Repair Robot

What is it?

Sewer systems require regular cleaning, inspection and maintenance. This is typically carried out manually for large sewers and by remote vehicles for small access sewers. However, existing tethered inspection robots have a relatively limited range due to the difficulties involved in pulling the tether. This means that access has to be gained at regular points along the sewer to be inspected, which, at the very least, requires more time and in the worst cases requires access holes to be dug.

Sewer inspection and repair robots will undertake inspection through large sections of sewer autonomously and will have the capability to perform interim repairs.

What applications does it enable?

Sewers need to be regularly inspected and cleaned in order to operate efficiently. In addition, Europe has some of the oldest sewers in the world with concomitant maintenance requirements. Apart from main storm sewers, most sewers are inaccessible for direct human entry or would be considered hazardous for such entry. Inspection of sewers is therefore carried out using some form of remote technology. Most inspections are carried out with small, remotely operated vehicles fitted with a camera on a pan and tilt head. Due to limitations on dragging the umbilical these systems can be operated some 100 to 300 meters from the access point. While this is usually sufficient for investigation of a specific problem, the routine inspection of miles of sewer can require many accesses and take a long time.

The current opportunity is for an autonomous system which can travel long distances through pipe systems, navigating autonomously and recording and noting the state of the sewers. Additionally, by enabling the sewer robot to perform minor cleaning and repairs, further expensive interventions can be avoided.

Market overview

The market in the UK is largely the water companies who own the sewers together with individuals and companies who own the parts of their own sewer connecting to the public sewer.

Sewer inspection is largely undertaken by specialist companies who undertake the service on behalf of the water companies or individuals.

Worldwide sales of robots for sewer inspection in 2006 were approximately USD18.5 million. Sales of USD86 million are expected between 2007 and 2010[26].

What are the unmet needs?

- Routine inspection of sewers to maintain optimum performance.
- The capability to autonomously navigate long distances within a sewer network, noting the state of the sewer
- The capability to clean and carry out interim repair operations to maintain the efficiency of the sewer and prevent more significant problems.

Market barriers and enablers

- Drivers and enablers
  - Improved productivity and increased sewer life
  - Lower inspection costs.
- Barriers
  - Specific technology barriers such as the ability to perform effective interim repairs with limited on-board storage and stored energy.

Timescale (market window)

A potential market exists currently. Exploitation is limited primarily by the development of the technology. To offer significant additional benefit to the end customer would require the development of repair capability and improved tracking. Such developments would be expected within a four to six year time window.

Key players

The key players in this market are the specialist inspection companies such as Underground Inspection Systems, Lanes for Drains, Freeflow Limited and Subscan.

Recently robotic sewer robots have started to appear from companies like Cybernetix, Everest, Inuktun, ISE, Jenoptik Silmetric, Omnitech, Redzone Robotics and RoboProbe Technologies. However, while some of these are capable of performing cleaning, none carry out repairs.

Conclusions

A significant potential market exists for a sewer inspection and repair robots with well established access to the market through the existing inspection companies. However, as the main benefit will accrue to the water companies owning the sewers, not the inspection companies directly, the water companies would have to be targeted if significant penetration of the market is to be made.

3.10 Nuclear Facility Inspection Robots

What is it?

This opportunity is for multiple small robots, each carrying relatively simple sensors to carry out facility audit and inspection of nuclear facilities prior to decommissioning and to build a geometric and radiological map of the contents of the facility to allow efficient decommissioning.

What applications does it enable?

The UK has significant nuclear assets to decommission. These include nuclear power plants but more specifically processing buildings at sites such as Dounreay and Sellafield. With older plants, the actual state of the plant and its contents is often not fully known and estimates have

[26] World Robotics 2007

to be made to allow decommissioning to proceed. These estimates include contingency factors to cope with the uncertainty of what may be found while decommissioning proceeds. Although the UK is at the forefront of decommissioning at present, the same issue can be expected to arise in the future in all countries with ageing nuclear power facilities.

Detailed inspection could reduce these contingencies and allow the development of the most efficient decommissioning plan and tools. However, access is often difficult and introducing large scale measuring and sensing equipment can be a costly exercise in itself. The identified opportunity is to undertake such inspection using small, low-cost robots equipped with relatively simple sensors that, in combination, will provide a fairly detailed inventory and map of the facility.

A closely allied opportunity is for a small underwater robot equipped with sensors to scan the bottom of nuclear storage ponds to determine the state of the material and to estimate the size and position of the radiological content. This would permit a survey to be carried out, ideally with minimum disturbance of the pool floor, otherwise radioactive material could be brought closer to the surface temporarily diminishing the shielding effects of the water

Market overview

The stakeholders in different markets may well differ. This opportunity description focuses on the UK situation as it represents the initial geographic market opportunity.

The UK nuclear facilities in question are owned by the Nuclear Decommissioning Authority (NDA) and are operated by site licensees, which in the case of Dounreay and Sellafield are the United Kingdom Atomic Energy Authority (UKAEA) and British Nuclear Group respectively. Development of the plan to decommission the facilities is jointly undertaken by the NDA and the site licensees, and the decommissioning programme is carried out by the site licensees in conjunction with their first tier suppliers.

Decisions on the speed and spend of decommissioning are largely government driven but there is a strong Treasury interest in containing the costs.

The estimated UK market for nuclear decommissioning alone is worth some GBP70 billion at the last estimate[27].

What are the unmet needs?

- Quantification of decommissioning costs based on facility inventories
- The ability to perform comprehensive surveys using relatively simple systems and low-cost small scale penetrations
- The ability to perform underwater inspection and thorough sludge sensing without disturbing the sediment.

Market barriers and enablers

- Drivers and enablers
    - Survey-based determination of the size of the decommissioning liabilities
    - The potential for cost reduction through better characterisation of the decommissioning problem
    - The political need to present the nuclear decommissioning task as a quantified and known liability.
- Barriers
    - The conservatism of the nuclear industry which may be nervous about new methodologies for the assessment of the size of the nuclear liabilities
    - Specific technology development barriers such as accurate navigation using low cost sensors, data fusion using low cost sensors and ensuring coverage in difficult to traverse environments.

27 http://news.bbc.co.uk/1/hi/business/4859980.stm

Timescale (market window)

In order to impact upon the current decommissioning planning process a deployable system should be available by the time the eventual long term storage issue is determined as this is probably the last time the cost estimates will be re-analysed on a major scale. There is currently no evidence that this is going to be settled in the near future but the expectation could be for between 2012 and 2016. After this point the ability to interest the government in a system to re-assess costs will be much reduced.

Key players

The key players in the UK are the main contractors to NDA, UKAEA and British Nuclear Group. These include Doosan Babcock, NIS, AMEC and INS Innovation.

Conclusions

There is a very large current liability with a strong political interest in establishing costs which will not rise further. In the UK it would be necessary to have NDA backing for the adoption of this approach. While full commercial adoption in the UK may prove challenging in the near term, it may be very valuable as a technology showcase in enabling longer term market opportunities. However, should existing estimating techniques be found inadequate, UK commercial deployment could still be possible.

3.11 Assisted Living/Elderly Care Robot

What is it?

This opportunity is for the provision of in-home robots to provide a limited range of functions for the elderly and disabled. Functions to be provided include assistance with sitting, standing and walking, reaching common objects such as plates and cups, simple fetch and carry tasks and simple interfacing with domestic appliances such as kettles.

What applications does it enable?

Elderly and disabled people, particularly those living alone, often reach a stage where independent living becomes difficult due to the difficulty of carrying out common, but often trivial, tasks. The options then are moving into managed care facilities, obtaining very regular support services or relying on family support. For many, none of these options is attractive as they lose independence and each can be costly for the person, their family or the state.

The opportunity is for a robot system that can carry out some of these simple tasks that will enable the person to stay within their own home for longer. It should be stressed that it is not suggested that providing an all-purpose care robot is either feasible or desirable within the ITI time window. Rather it is seen that the robot would perform some of the routine functions that would not be supplemented by other support functions, such as occasional welfare or family visits. Thus, while a robot may be desirable to make a cup of tea anytime in the day, tasks such as doing laundry seem to be more viable to be undertaken by occasional human visitors.

The tasks that the robot would need to perform would be those that would be regularly required by someone who was mobile but might have difficulty in moving around the house and accessing certain objects. Thus tasks such as assistance with sitting, standing and walking would be high priorities. Accessing such items as cups, plates and TV remote controls would also be highly desirable. Performing general fetch and carry tasks would be useful and simple interfacing with domestic appliances such as kettles and microwaves would be an added benefit.

While this range of tasks may seem ambitious for a home robot they are offset by the costs of alternative support. The cost of managed care for the elderly in the UK is estimated to range from around GBP25,000 to GBP100,000 per annum. The severe cost constraints normally associated with domestic robots are put in proportion and the case for a return on the investment decision with a relatively expensive device can be undertaken.

Market overview

The market is potentially complex with, on one side the individual and their family, and the other the whole managed care industry and, potentially, the government.

While making the case for a robot on an individual basis may be possible (particularly for a leased system), it is through offsetting potential government costs for state sponsored managed care that the potential for a large market can be anticipated.

The UK elderly care market is currently GBP20 billion[28] per annum and set to grow as the population ages over the next 40 years. By 2030 20% of the US population will be in managed care[29]. However, Japan, Korea and Italy have a more critical problem and will present larger potential markets in a shorter timescale.

What are the unmet needs?

- Maintenance of independent living and personal dignity
- Managing and containing potentially spiralling costs of an aging society
- The provision of affordable flexible support services within the home on a 24/7 basis.

Market barriers and enablers

- Drivers and enablers
    - The maintenance of quality of life and independent living
    - Containment of potentially spiralling state support costs
    - Providing manageable support targets for family members.
- Barriers
    - Lack of acceptance by the target support group, i.e. the elderly
    - Lack of effective safety regulations allowing cooperative working between robots and humans could delay practical implementation
    - Ethical issues regarding the lack of human support for the elderly could confuse the market.

Timescale (market window)

This market is one that is going to grow. However, pressure will increase on government budgets over the next 10 years. Also pressure for finding a solution in countries such as Japan, Korea and Italy, who will face severe problems earlier, mean that a late market entry may face too much competition to establish a reasonable market share. For these reasons it is suggested that the correct time to seek entry into the market is between 2014 and 2018.

Key players

Although there are some suppliers of rehabilitation robots (e.g. PALS Robotics, Independence Technologies and Rehabilitation Technologies) and, in the Far East, some elderly care robots, none of these yet have the full characteristics necessary to support independent living in the home.

The key players in the development of the UK market will be the UK central and local governments and those responsible for the provision of care, such as Social Services.

Conclusions

This is a very large market with potential for a large home base and significant export markets. Although the technology will be difficult to engineer in a safe and acceptable form, the approach

[28] Laing and Boissan Care of Elderly Market UK Survey 2007

[29] US Department of Health and Human Services. Available at: http://www.aoa.gov/prof/Statistics/statistics.asp.

of providing the minimum functions necessary to support everyday living for a partially mobile person should allow successful development.

With respect to exploitation, the costs of alternative care arrangements make this the one domestic robot that is currently capable of supporting a relatively high sales cost, approaching that of many professional service robots. Finally this application will be an important precursor for developing the technologies of the longer term general home robot and getting the idea of home robots firmly established within society.

3.12 Market Opportunities Not Prioritised

Figure 11 below lists the areas that were assessed but were not considered to offer the greatest opportunity. The key reason for not pursuing these areas is highlighted.

Opportunity	Summary	Key reason for not prioritising
Nano assembly robots	Robots for the production of prototype and small scale nano assemblies and systems	Market does not exist and is unlikely to mature in the ITI timeframe
Minimally invasive joint replacement	Robots for assisting with joint replacement operations	Some existing competition and difficulties with gaining medical device approval
Intra-operative tracking compatible robots	Robots to be used within an operating MRI, CT or X-ray fluoroscopy system	Development would take this beyond the ITI timeframe
Low-cost trans-pubic radical prostatectomy robots	Robots specifically designed only for prostatectomy operations	Specific opportunity which could enter product development without significant enabling funding
Intelligent wheelchairs	Wheelchairs for severely disabled people featuring advanced user interfaces	Route to market unclear
Handicap assistance robots	Robots to assist with eating, drinking and operating equipment	Several prototype devices already exist. Differentiation would be difficult
Cognitive therapy robots	Robots to engage patients in interactive behaviour for therapeutic purposes	Uncertain market
Bridge inspection robots	Robot for the inspection of bridges	Interesting but limited market
On demand transportation	On demand mass transport for public areas	Exploitation beyond the ITI timeframe due primarily to certification and approvals
Intelligent demolition robots	Demolition robots with capability of semi-autonomous operation	Uncertain market
Landfill characterisation robots	Robot to survey and characterise the content of landfill sites	Interesting market with potential spin-offs but unclear route to market
Landfill remediation robots	Robots to sort, segregate and repackage hazardous landfill waste	Capability could not be developed within the ITI timeframe
Personal underwater robots	Semi-autonomous robots for personal exploration of sea-bed etc	Limited market with existing, but lower technology, competitors
Robotics application development platform	Development platform and kit for advanced hobbyist user	Difficulty in differentiating this from lower level kits and hobby systems
Minimally-invasive needle placement	Precise placement of needle inside body cavity/head for delivery of drugs/ radioisotopes	Limited opportunity with little spin-off potential

Figure 11: Non-prioritised market opportunities [Source: ITI Techmedia]

4 CONCLUSIONS AND NEXT STEPS

This section includes a short conclusion to the report together with the next steps that ITI Techmedia will take to investigate opportunities arising from the Advanced Robotics foresighting activity.

4.1 Conclusions

This Report has reviewed the Advanced Robotics market using an application-focussed approach. Within the next 10-15 years Advanced Robotics is expected to impact increasingly on everyone, both at home and in the workplace. This is a technologically complex emerging market with significant opportunities for the right application.

Advanced Robotics technologies, systems and products have developed to the point where a number of market applications can already be exploited. However, a number of issues - such as the current cost of robotic systems and unresolved health and safety issues in a co-operative human-machine environment - makes wider application in the home and professional environments challenging. However, as and when such issues are resolved, the opportunities for advanced robotics systems will flourish.

As market opportunities become addressed through technologically novel, economically-viable products, the Advanced Robotics market will witness significant growth in the medium to long term. Indeed, by 2025, the Advanced Robotics market opportunity could be worth over USD50 billion from a base of around USD6 billion in 2006.

As with any opportunity that offers significant new commercial opportunity, the emergence of aggressive small companies and start-ups can be expected. As such, the Advanced Robotics market could represent a significant new and addressable opportunity for technology businesses in Scotland.

Through the creation of underlying technology platforms, ITI Techmedia could play a role in enabling the development of such businesses. As such, ITI Techmedia has identified nine opportunities that could lead to the creation of technically novel and commercially exciting enabling technology platforms.

Further to this opportunity identification, subsequent analysis has indicated that the following opportunities could form the basis for further ITI Techmedia activity in this area:

- Human-robot co-operative assembly (possibly incorporating aspects of large structure assembly)
- Nuclear facility inspection robots
- Assisted living / elderly care robots.

4.2 Next Steps

Prior to progressing activities in this area, ITI Techmedia will seek to engage with ITI Members to validate and confirm those opportunities that should form the basis for its subsequent activities. In addition, ITI Techmedia welcomes R&D programme proposals and expressions of interest in related areas to assist in providing an understanding of the capabilities and commercial interest within Scotland.

If you are interested in future engagement in the area of Advanced Robotics, how to make a proposal or provide an expression of interest relevant to this area, please contact Jiansong Yu, Market Analyst, ITI Techmedia (jiansong.yu@ititechmedia.com).

APPENDIX A: GLOSSARY OF TERMS

Domotics	Information and communication technologies supporting home automation
Haptics	The science of touch and associated sensory feedback obtained through the skin and musculature
Industrial Robots	Robots designed to work in an industrial workplace which, generally, perform a preset task that is explicitly defined by a software programme
Infotainment	An application providing both information or educational content while at the same time being entertaining
Nano-Robot (or nanobot)	A robot that is built to the nanometre scale or is designed to manipulate objects at the nanometre scale
Network-centric	A form of collaborative endeavour based upon the widespread collection and sharing of data and information
Micro-robot	A robot built to the millimetre scale or largely containing components manufactured at this scale
Service Robot	A robot designed to operate in a general environment containing previously unknown features and objects and possibly, humans, which must be capable of reacting to unplanned events and situations
SLAM	Simultaneous Localisation And Mapping. A method of both building maps and localising one's position in an unknown environment
SME	A Small or Medium-sized Enterprise
UAV	Unmanned Air Vehicle
MRI	Magnetic Resonance Imaging

APPENDIX B: OPPORTUNITY ASSESSMENT CRITERIA

Section 3.1 refers to 10 assessment criteria that were used to rank 60+ opportunities and create a short-list of nine. These assessment criteria were divided into six with commercial potential and four with innovation potential. The commercial potential criteria are presented in the three tables below.

	Demand Side	
Score	Size of addressable market segment and potential market share	Medium-term industry growth rate
0	< GBP100 million and < 5%	Declining market, negative growth
1	< GBP100 million and > 5%	Mature market, low growth
2	> GBP100 million and < 5%	Early adopter phase, high growth
3	> GBP100 million and > 5%	Nascent market or established market + disruptive technology

	Supply Side	
Score	Competitive advantage	Industry characteristics
0	Not competitive; does not meet a market requirement	Active large corporates with significant market share
1	Incremental improvement; meets some market requirements to some degree	Established market leader
2	New product offerings possible or significant cost savings; meets major market requirements to some degree	Highly fragmented or no significant activity
3	Step-change; meets major market requirements to a high degree	Some competition, no clear market leader

Score	Upside Market Opportunities and Timescale	
	Multitude of applications per platform	Timescales to first revenues
0	One application in one market sector	Short term (under three years)
1	Multiple applicability in one market sector	Long term over ten years)
2	One application in a number of different market sectors	Medium term (between three and ten years)
3	Multiple applicability in a number of different market sectors	Medium term (between three and ten years)

The four innovation potential criteria are given in the box below:

Score	Technical risk and level of maturity	Technology uniqueness	Quality of IP	Protectability of IP
0	Technical concept not yet proven or well-proven and product development-type work	Undifferentiated	Cannot keep secret or cannot protect	Cannot protect
1	Some technical hurdles to overcome or engineering-type work	Many competitive offerings or busy patent space	Easily replicated	Hard to protect
2	Technical concept proven; further substantial development required, but largely unclear	Unique technology and one of a few competing solutions, or, low, emerging patent activity	Difficult to replicate	Easy to protect
3	Technical concept proven; further substantial development required and tasks clearly identified	Unique technology with clear benefits, and, low, emerging patent activity	Can keep secret/proprietary	High quality, unique, patents possible