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Mobiles Robots – Past Present and Future

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1. Introduction

Since their introduction in factories in 1961, robots have evolved to achieve more and more elaborate tasks. The industrial robots now account for a 5 billion dollars market. Positioned along the assembly line, a robotic manipulator can perform tedious and repetitive tasks such as welding, painting, moving or cutting with immense speed and incredible accuracy. As an example, their use in the automotive industry has drastically cut the time it takes to assemble a vehicle.

Since the introduction of the first industrial robot UNIMATE online in a General Motors automobile factory in New Jersey in 1961, robots have gained stronger and stronger foothold in the industry. Several milestones are worth noting since then:

The first artificial robotic arm to be controlled by a computer was designed. The Rancho Arm was designed as a tool for the handicapped and its six joints gave it the flexibility of a human arm.

DENDRAL was the first expert system or program designed to execute the accumulated knowledge of subject experts.

1968 - The octopus-like Tentacle Arm was developed by Marvin Minsky.

1969 - The Stanford Arm was the first electrically powered, computer-controlled robot arm.

1970 - Shakey was introduced as the first mobile robot controlled by artificial intelligence. It was produced by SRI International.

1974 - A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was designed.

1979 - The Stanford Cart crossed a chair-filled room without human assistance. The cart had a TV camera mounted on a rail which took pictures from multiple angles and relayed them to a computer. The computer analyzed the distance between the cart and the obstacles.

It is no surprising that in face of diverse configurations, functions, applications, and autonomy there is no agreeable universal definition of “Robot”. The well-known definition of Robot from the Robot Institute of America (RIA) is that a robot is

"A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks".

It at best describes industrial robots and applications – not all robotic applications are associated with “move things”. “Programmed motions” may have to be augmented for mobile robots that often decide their motion/part based on their situational awareness. A more inspiring and general definition can be found in Webster. According to Webster a robot is:

"An automatic device that performs functions normally ascribed to humans or a machine in the form of a human."

The Webster definition broadly covers robotic tasks and functions beyond moving things as in RIA definition. Being a subset of robots, one may consider that defining mobile robot would be easier and more accurate. Indeed, Wikipedia has this definition:

“A Mobile Robot is an automatic machine that is capable of movement in a given environment.”

As opposed to fix based industrial robots, a mobile robot has its movement unlimited by its physical size due to its mobility. As a result, mobile robots can operate in a large workspace and explore unknown environments and therefore are able to perform tasks wherever needed. They have been used to perform a variety functions that are normally performed by humans or a machine in the form of a human, such as surveillance, exploration, patrol, homeland security, domestics helper (e.g. lawn mower), butler, care taker, and entertainer.

The recent decade has witnessed an explosion of research activities in mobile robotics. By and large, mobile robots can be categorized into three categories according to their operating environments: i) land (based) robots, ii) aquatic/underwater robots, and iii) aerial (air, flying) robots; each of them possessing sub-categories

Because of the need to operate in unknown and/or uncertain environments, mobile robots demand much higher level intelligence than traditional industrial robots. These requirements have been met by the phenomenal advancement in silicon technology and computing power. The rapid reduction in both size and cost of integrated chips has raised a huge interest for scientists to create intelligent systems.

This chapter provides an overview on mobile robotics. Instead of attempting to cover the wide area of this subject exhaustively, it highlights some key developments. Firstly, a functional model of generalized robots is presented, and serves as a common conduit which helps the analysis and comparison of robotics technology. It then paints a global perspective of mobile robotics market, followed by historical development highlighted by some key milestones. Subsequently, the chapter presents the state-of-the-art in mobile robotics research, and summarizes the works presented in this book. Some critical reflections and challenges ahead are highlighted as far as future development is concerned. Finally conclusions are drawn.

2. Functional model of generalized robots

A generalised robot or robotic system possesses a set of functional parts similar to human beings. As shown in Fig. 1, these functional parts include intellectual, statue, motivational, actuation, sensory, communications and energy.

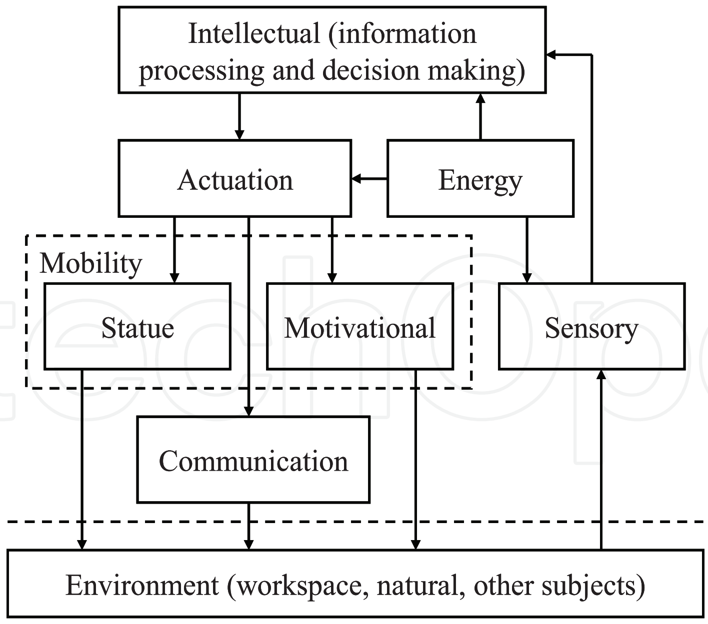

Fig. 1. Functional model of generalised robots

The functional model in Fig. 1 clearly illustrates the energy forward path and information feedback path. The intellectual part commands the actuation part, which in turn drives the mobility system - statue and motivational parts. Mobility is achieved through statue and motivational parts driven by actuators. Statue refers to body frame (skeleton) in case of a human being, and mechanical frame for a robot. In industrial robots, the mechanical frame is the mechanical links linked through joints. In mobile robots, the mechanical frame is the airframe for aerial robots, hull structure for underwater vehicle, and chassis for land vehicle, mechanical structure for humanoid robot.

Motivational parts are accessory mechanical parts to robots and limbs to human beings. They either enlarge or refine the robot mobility to execute specific tasks. Wheels, tracks, propellers increase the range of robot movement well beyond its statue. Grippers and end-effectors enhance the dexterity of the workspace and manipulation. Like a human, a robot accomplishes a delicate task like assembly, welding, and polishing by being equipped with motivational parts.

In accomplishing a defined mission, a robot, through its statue and motivational blocks, physically interacts with its operating environment. Robot operating environments can be classified into the following three categories:

Pre-defined and structured environment. The robot has all the knowledge about the environment and objects to deal with. It typically exists in factory automation

Semi structured environment. The robot has some pre-knowledge (e.g. GPS maps) about the environment, but it may change spatially and temporally. An example would be surveillance robot which tours its familiar territory, but the environment and objects inside it may change spatially and temporally.

Unstructured environment. The robot has no priori knowledge about it, with underwater being an example. The robot has to rely on its powerful sensory and navigation system to operate autonomously. A practical approach would be semi-autonomous system which accepts remote intervention from time to time.

In the energy forward path, a robot exerts energy onto the environment. In this process, the primary energy source (typically electrical) is converted to other types of energy such as

kinetic, mechanical, wave, etc while a task is performed by the robot. In this process, the robot communicates with the environment through data, image, video or sound. It receives situational information through its Sensory functional block, which closes the control loop.
Although both robots and human beings possess the same set of functional blocks, hence have correspondence in each block. A parallel drawn between robots and human being in terms of realisation of these functions is shown in Table 1. It is apparent that for a robot to perform similar tasks like a human being, it indeed needs to possess the seven essential functional parts. Nevertheless, for simple applications in a more deterministic operating environment some of the functions such as sensory function are reduced to minimal.

Functional Blocks	Human Beings	Robots
Intellectual	Brain	Microprocessor (computer hardware and software)
Statue	Skeleton	Mechanical frame (airframe, chassis, hull).
Motivational	Limbs	Wheels, legs, tracks, propellers, grippers, etc.
Actuation	Muscles	Hydraulic, electric, pneumatic. piezoelectric, electrostatic actuators; artificial muscles.
Sensory (perception)	Eyes, ears, skin	Cameras, optic sensors, sonar, sound, infra-red light, magnetic fields, radiation, etc.
Communication	Speech, gesture	Data, image/video, sound
Energy	Food / energy storage	Power source / energy storage.

Table 1. Robots versus human beings: functional blocks

As a result, a mobile robot is a complex assembly of fundamental building blocks, each of which has to be carefully chosen based on specifications such as terrain, mission duration, goal and atmospheric conditions. The “optimal” design aims for the robot to accomplish a specific mission most cost effectively and efficiently. In contrast, a human being always uses the same set of “functional bocks” to accomplish any type of missions - marathon, sprinting, assembly, inspection and entertainment.
The mobility system accomplishes certain tasks by interacting with its operating environment, known or unknown. It is therefore important to take the various functions into consideration when design a mobile robot.
Mobility: Mobility in mobile robots requires mechanical frame and motivational parts. Another consideration is to give the mobile robot locomotion capabilities based on its deployment environment and missions. If the robot will only encounter smooth ground, wheels or tracks would be reasonable. Rougher terrain would require bigger wheels. In search and rescue mission in debris, leg locomotion is desired.
Sensors: A large collection of sensors are available to detect information about the environment. They can be used for monitoring purposes (chemical sensors, thermometers) or to help the robot to maintain its operations (accelerometers, GPS, etc…).
Actuators: They allow the robots to perform extra tasks besides mobility.

On-board Computation: Depending on its purpose a mobile robot will require more or less advanced on-board computation. Simple robots will just need steering computation capabilities whereas robots interacting with humans will require advanced electronics to successfully communicate.
Software: The software includes all the processes required by the robot to operate. They range from low level mobility processes up to behavioural processes.
Energy: Mobile robots usually operate in remote environments where energy is not readily available. Carrying the necessary energy to finish the assigned task is a necessary condition when creating a mobile robot.
Communication: In many applications, communication is essential to a mobile robot. It can be used to monitor the robot, to communicate with other robots or to communicate information.

3. Global perspective of mobile robotics market

They are several identified markets for mobile robots: service and military robots.

3.1 Service

Service robots are usually divided into 2 sub-categories: Professional and Domestic robots. The first one includes robots designed to serve either humans or equipment. As an example, medical robots can be used to assist for surgeries as well as help for the training of surgeons. Robotically-assisted surgery systems markets are supposed to have rapid growth. The market that was at $626.5 million in 2007 is anticipated to reach $1 billion in 2008 and is forecast to reach $14 billion by 2014. Mobile robots are also developed to work as tour guides (Toyota's "Robina" or Fujitsu's "Enon").

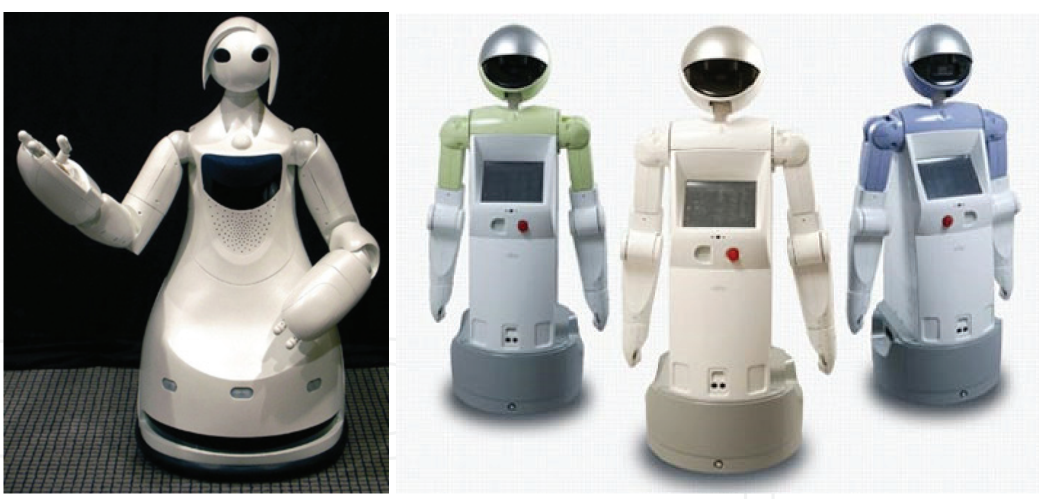

Fig. 2. Robina, Toyota's tour guide (left) and Fujitsu's Enon (right)

Service robots are also developing for equipment service such as pipe and window cleaning. They are designed to perform tasks such as inspection, maintenance and repairs.
The latter category of service robots is known as personal robots. It includes educational robots, home care, entertainment and home assistance. Educational robots are usually very versatile platforms that help students get a global experience with mobile robots. MobileRobots platforms represent a reliable base and powerful software that helps make students' robotics experiences a success. The market for educational robotic kits at $27.5 million in 2007 is forecasted to reach $1.69 billion by 2014. Home care robots introduced so

far are rather simple (vacuum robots such as Roomba® or lawn mowing robots such as the Robomawer®), but general purpose home-care robots are on the way. Consumer robot markets for house cleaning; lawn mowing, pool cleaning, and general home services reached $227 million in 2007 and are expected to attain $1.7 billion by 2014.

Fig. 3. The Roomba® robot and the latest Care-O-bot®

Entertainment robots such as robot toys represent a growing part of consumer electronics and toy robots are usually "Must-have" for many children during the Christmas season. A good example of the success of toy robots is Robosapiens from Wow Wee that sold over 4 million units.

3.2 Homeland Security and Military

Robots play a major part in the quest to automate military ground systems. They provide vital protection of soldiers and people in the field and will potentially reduce the number of fatalities in combat.

The use of remote-control robots in Iraq started as simple robots to investigate possible roadside bombs. Since then, a lot of robots have been developed to dispose of bombs in a combat or urban environment. Smaller and cheaper MARCBOTs and BomBots models are being engineered to provide even more help.

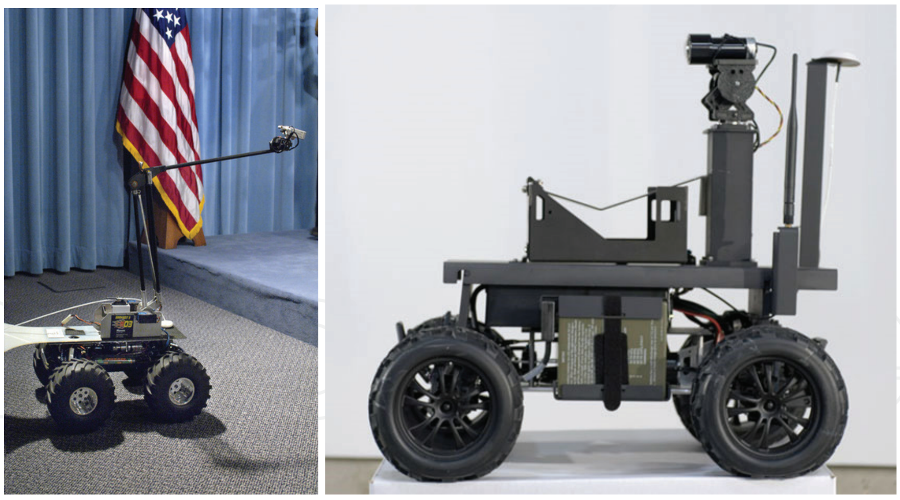

Fig. 4. Multi-Function Advanced Remote Control Robot (MARCBot - left) and BomBot (right)

The U.S. Department of Defense (DoD) released a report in 2007 that investigates at the future of military's unmanned systems for the next 25 years. This report puts into perspective the most urgent needs that are supported both technologically and operationally by various unmanned systems. These needs are listed below and should be considered by researchers as they will probably represent a large amount of funding from the DoD.

1. Reconnaissance and Surveillance.

Unmanned systems will play an important role in the field of reconnaissance, both electronic and visual. It has become essential for troops to be able to survey areas of interest while being under cover. Efforts should be made to increase the standardization and interoperability of unmanned systems as the number and diversity of users is going to increase significantly.

2. Target Identification and Designation.

Identification and localization of military targets are still to be improved as they are critical. A mistake usually results in the non-destruction of a target or worse, the death of innocent civilians. It is therefore important to reduce the latency and increase the precision of GPS guided weapons. The capability of unmanned systems to operate in high threat environments is not only safer for troops but potentially more effective than the use of current manned systems.

3. Counter-Mine Warfare.

The military authorities have pointed that sea mines have caused more damage to the fleet than all other weapons systems combined, and that Improvised Explosive Devices (IEDs) are the number one cause of casualties in Iraq. A lot of work has already been done to improve the military's ability to find, tag, and destroy both land and sea mines, and unmanned systems naturally seems to be the solution to fulfil these missions.

4. Chemical, Biological, Radiological, Nuclear, Explosive (CBRNE) Reconnaissance.

Efforts should be made in developing unmanned systems able to identify and locate chemical and biologic agents and to survey the extent of affected areas.

The military robots markets were $145 million in 2007 and are anticipated to reach $6.9 billion by 2014.

4. Historical development of mobile robots

4.1 Evolution from fixed base robotics to mobile robotics

Interest in mobile robotics mainly comes from the need to explore areas that humans cannot explore. The reason may be that the environment is hazardous (radioactive, at deep sea level) or too far in distance and time (space exploration). Under such conditions, fixed-based robots are not sufficient.

4.2 Milestones of autonomous ground vehicle

Grey Walter's tortoises (1948-9, Bristol)

Grey Walter tortoise was an attempt to demonstrate that rich interconnection between a small amount of brain cells has the potential to create to complex behaviors. His first two robots, which were called "Machina Speculatrix", were developed between 1948 and 1949 and were named tortoises because of their shape and speed. These very early three-wheeled robots were indeed capable of photo taxis (they could find their way to a recharging station when they were low on power).

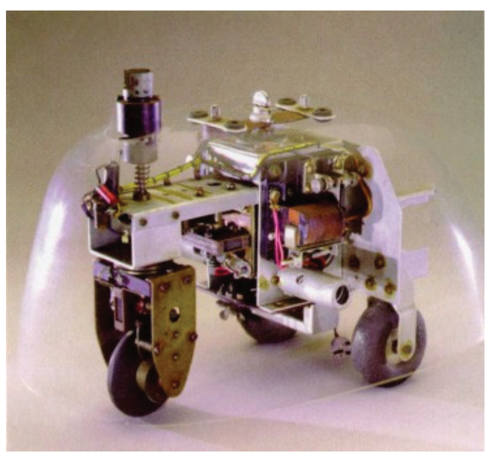

Fig. 5. Reconstitution of Grey Walter's tortoise

Shakey (1968, SRI)

Shakey was the world's first mobile robot capable of "reason" by taking actions based on its surroundings. Shakey was equipped with a TV camera, a triangulating range finder, and bump sensors, and was connected to DEC PDP-10 and PDP-15 computers via radio and video links. The robot was using programs for perception, world-modeling, and acting. Low-level action routines took care of simple moving, turning, and route planning. Intermediate level actions strung the low level ones together in ways that robustly accomplished more complex tasks. The highest level programs could make and execute plans to achieve goals given by a user. The plans could be stored for possible future use.

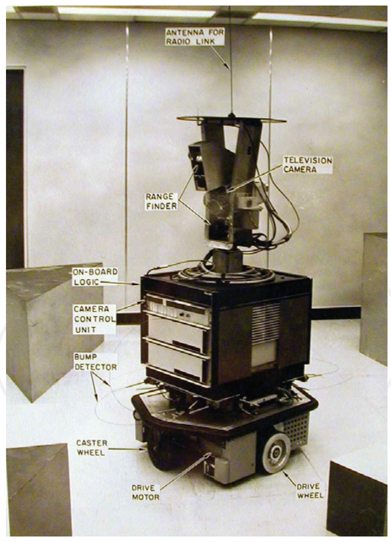

Fig. 6. Picture of Shakey

Stanford cart (1979)

In 1979, the Stanford Cart was able to cross a room full of chairs without human assistance. The cart was equipped with a TV camera mounted on a rail which took pictures from multiple angles and relayed them to a computer. The computer would then analyze the distance between the cart and the obstacles and steer accordingly.

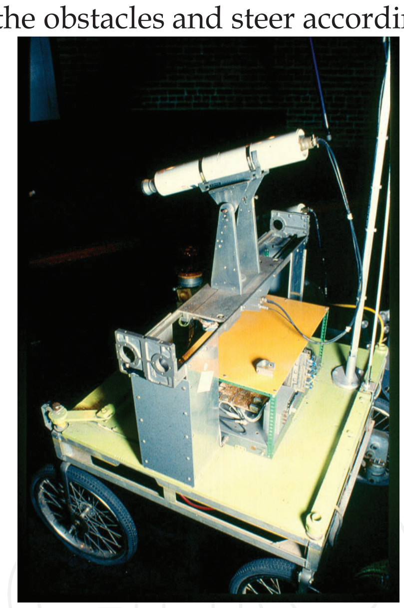

Fig. 7. Stanford Cart

Genghis (1988, MIT)

The Mobile Robots Group at MIT developed a six-legged walking robot named Genghis Khan, which was able to teach itself how to scramble over boards and other obstacles.

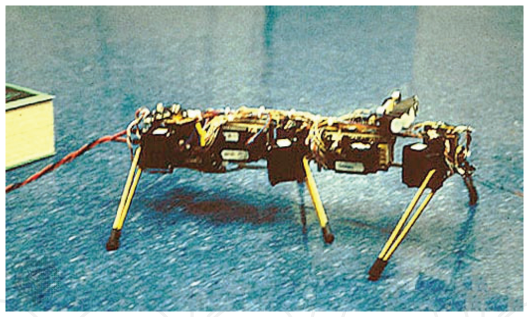

Fig. 8. MIT's Genghis Walking Robot

Khepera (1994, EPFL)
The Khepera is a small (5.5 cm) differential wheeled mobile robot that was developed at the LAMI laboratory of Prof. Jean-Daniel Nicoud at EPFL (Lausanne, Switzerland) in the mid '90s.

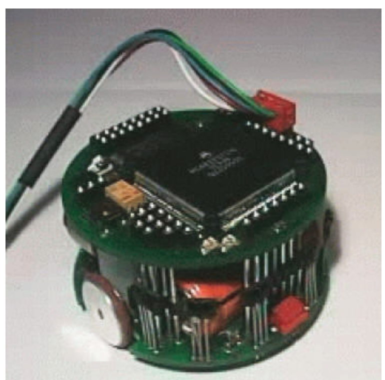

Fig. 9. The Khepera Robot

Stanley (2005, Stanford)
Stanley is an autonomous car, winner of the 2005 DARPA Grand Challenge (>200km in desert paths in ~7h). The vehicle incorporates measurements from GPS, a 6DOF inertial measurement unit, and wheel speed for pose estimation. The environment is perceived through four laser range finders, and a monocular vision system. Map and pose information are incorporated at 10 Hz, enabling Stanley to avoid collisions with obstacles in real-time.

Fig. 10. Stanford Autonomous Car "Stanley"

4.3 Milestones of unmanned aerial vehicles

1916: aerial torpedo - Hewitt-Sperry Automatic Airplane
The Hewitt-Sperry Automatic Airplane project was started during World War I. Its purpose was to develop an aerial torpedo, carrying onboard components capable of sustained flight over a long period of time without the need of human manipulation. The "brain" of this

unmanned vehicle consisted of gyroscopes, mechanically coupled to the aircraft control surfaces so as to maintain its stability.

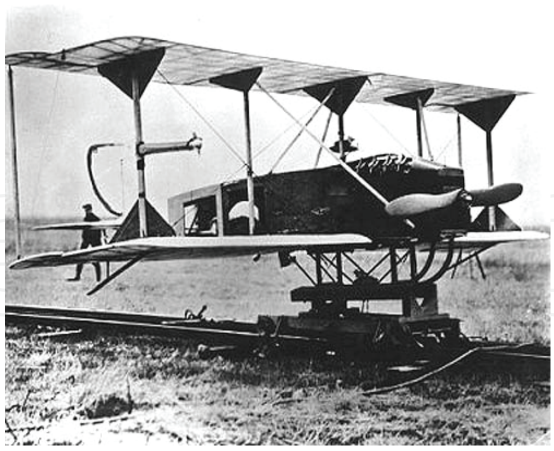

Fig. 11. The original Sperry Aerial Torpedo, 1918

1923: Pilotless Airplane
In 1923, the Army Air Service announced that a pilotless airplane, equipped with an automatic control device had been developed to a point where it has made successful flights of more than ninety miles. At the time, it was said to be more accurate and dependable than any human pilot.
1935: Drones and Radio Controlled Aerial Target
In 1935, a large number of RC targets were produced, the "DH.82B Queen Bee", derived from the de Havilland Tiger Moth biplane trainer. The prototype was first flown on January 5, 1935. The name of "Queen Bee" is said to have led to the use of the term "drone" for remote-controlled aircraft. These were used as targets for military anti-aircraft gunnery practice.

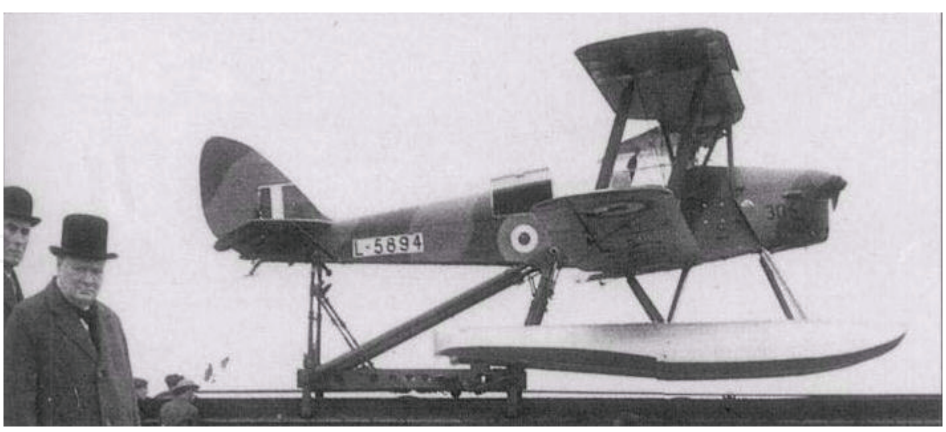

Fig. 12. The De Havilland DH.82B Queen Bee

1956 : Surveillance Drones
Drones used as target were successful and this led to it being used for other purposes. The Ryan Firebee was a good platform for test experiments, and tests to use it for reconnaissance missions were successful. A series of reconnaissance drones derived from the Firebee, known generally as "Lightning Bugs", were used by the US to spy on Vietnam, China, and North Korea in the 1960s and early 1970s.

Fig. 13. Firebee Lightning Bugs

1964: Unmanned Combat Air Vehicle
In 1964, "Project CeeBee" was created to experiment using a Firebee, fitted with underwing pylons, to carry two 115 kilogram (250 pound) bombs. The Firebee was launched from a ground station, using a booster for initial propulsion. However, the CeeBee experiments were not successful enough; the cause being that shooting at a target proved much more complex than flying over an area and taking pictures. The very first launch of a missile, a Maverick, from a UAV occurred on 14 December 1971, thanks to more advanced guided munitions.
1992: Miniature UAVs (MAVs)
During the early 1990s, the idea that small UAVs could be of interest was introduced. DARPA started a 35 million dollar project to develop and test a UAV. The specifications were that the MAV needed to carry a night / day imaging device, and operate for at least 2 hours. This study came to an end in 2001, and DARPA then investigated commercial vendors capable of producing MAVs to the initial design specification.
The majority of modern MAVs are designed to be smaller than conventional UAVs, but not as small as originally envisioned. Most UAVs used by the military and government organizations are hand launched units, able to be transported, deployed and operated by a single user. Smaller MAVs are still under investigation, but currently the majority of used MAVs are on the larger side.

5. The state of the art in mobile robots

5.1 Design methodology

The development of any type of mobile robot is challenging and takes a lot of time and considerations. It would be possible to improve the productivity of the development work by optimizing the design methods and tools.
The design process of a mobile robot can be divided into three logical parts based on its architecture: software, hardware and mechanical.
The software is usually divided hierarchically into two parts:

High level software that allows the mobile robot to function autonomously and fulfil its designated mission.
Low level software includes the basic motor functions such as the steering algorithm as well as reflex functions like communication routines or collision avoidance programs.
To create the software architecture, the most common approach is to replace the sequential programs into a collection of simple, distributed, and decentralized processes with capability for each to access information from sensors as well as to send commands to the actuators of the robot. This approach was first introduced under the name "subsumption architecture" and was proposed by Rodney Brooks at MIT. Local behavioural routines run constantly in parallel using only local available information. The emergent overall behaviour turns out to be flexible and robust. All these emergent approaches are based on biological systems. They try to mimic mechanisms from biological systems, especially adaptive behaviours. Adaptation, combined with a decentralized bottom-up approach, is often seen as a solution to the problem of generating and maintaining stable behaviours in partially unknown and dynamic environments.
The hardware part is twofold. Electronics parts, such as digital, analog and power electronics components, are used to convert software requests into actuator control signals and to scale and digitize sensor signals. Actuators provides mobility to the robot by transforming its input signal, likely electrical, into motion. The types of actuators used for mobility have to careful chosen depending on the environment where the mobile robot will ambulate (air, land, sea). Sensors are used to measure a physical quantity from the environment and convert it into a signal used either for locomotion or monitoring a variable of interest.
The mechanical part can be divided in two. Mechanisms can be used to transform the movement of the actuators; for example change the rotational movement of a motor into a translational one. The body is designed to protect the main parts of the robot from the environment; it gives the robot its integrity.

5.2 Perception and situational awareness

The terms such as perception and awareness have been replaced by the more general term "cognition". In robotics, cognition includes the creation of high level information from the combination of low level pieces of information and memory. Such high level information can be a "mental" map of the surroundings as well as a prediction of the future evolution of that environment. Cognition also requires different types of behaviour such as planning, sensing, recognition, learning, coordination and other "human-like" tasks.
There exist several possible states of cognition. To illustrate these different states, we introduce a cognition model found in (Patnaik, 2007). This model includes seven different mental states (sensing & acquisition, reasoning, attention, recognition, learning, planning, action & coordination) as well as two separate types of memory (short-term and long-term). The cognition is this model is realized by three cycles. These three cycles are the "acquisition cycle", the "perception cycle" and the "learning and coordination cycle".
The purpose of the acquisition cycle is to memorize the information from the sensors into a short-term memory. The data are then compared to what is known (i.e. stored in the long term memory) for validation. The perception cycle uses information stored in the long term memory to interpret data gathered during the acquisition cycle. Finally, the learning and

coordination cycle plans the future actions of the robot based on stored information of the surroundings.

In robotics, cognitive behaviours are achieved with the help of computing techniques. The most common pattern is that sensor readings are used by a micro-controller to steer the robots actuators so as to achieve a specific task.

Two of the most researched areas in perception are vision and recognition. To operate a mobile robot in an unknown environment, it is necessary to be able to analyze that environment to maintain the safety and integrity of the robot.

Whereas vision mostly depends on hardware, recognition is mostly based on computational techniques. Here is a list of recognition techniques:

Template matching: this technique is based on image processing where the image is scrutinized to find a match of a template image.

Feature-based model: instead of looking for templates, the image is analyzed to find some features or patterns. Such features are usually geometric shapes or specific colours.

5.3 Control of mobile robots

5.3.1 Formation Control

A large number of different strategies for formation control of a group of mobile robots can be found in the literature. Several frameworks stand out by the number of strategies that have been developed including the leader- follower schemes, behaviour-based methods, and virtual structure techniques. Between these three techniques, the leader- follower approach is the most acknowledged: one or more mobile robots are designated as leaders and are in charge of leading the formation, the other robots have no information about their headings and simply follow the leader(s): they are called followers. The followers usually try to maintain a set distance between them and the formation leader.

In the behaviour-based methods, the robots maintain formation thanks to two complementary processes: the first one , called detect-formation-position, computes the robot's ideal location within the formation based on sensor readings; the second one, called maintain-formation, generates the control commands to steer the robot toward the position determined by the first process. The virtual structure method uses the idea that points in space maintaining a fixed geometric relationship can be observed as behaving in the same way as points on a rigid body moving through space. When robots behave in this way, they are moving inside a virtual structure.

5.3.2 Control of non-holonomic mobile ground robots

Nonholonomic robots dynamics are characterized by equations involving the time derivatives of the system’s variables and constrains. These dynamic equations are non integrable. Nonholonomy is usually encountered when the system has less control inputs than controlled variables. As an example consider a wheeled mobile robot that has two controls (linear and angular velocities) while the domain it evolves in is 3-dimensional. Therefore, every feasible control signal does not necessarily correspond to a feasible path for the system. This is the reason why the geometry-based techniques developed in motion planning for holonomic systems cannot be directly applied to nonholonomic ones.

The purpose of motion planning is to obtain open-loop controls to steer a nonholonomic mobile robot from an initial state to a desired final state along a feasible trajectory that is possibly optimal. The principal motion planning techniques can be classified as differential geometric, geometric phase, and optimal control. Differential geometric techniques are based on an extended set of equations for the system in conjunction with the original one. A first control sequence is computed from the extended system and is used to create the final control input used on the real system. Geometric phase techniques use the concept of holonomy and path integral along an m-polygon to transform the differential constraints of the system to algebraic geometric phase equations. The optimal control path planning problem is usually formulated as a two point boundary value problem with various problem constraints. The optimization criterion being minimized is a control performance index which can include energy saving, formation, collision avoidance or bang-bang conditions. This technique can easily be extended to robots moving in a three dimensional environment.

Obstacle avoidance can also be considered and increases the motion planning's difficulty. The methodology then needs to take into account both the constraints due to the obstacles and the nonholonomic constrains. It appears necessary to combine geometric techniques addressing the obstacle avoidance together with control theory techniques addressing the special structure of the nonholonomic motions.

Readers can refer to (Li and Canny, 1993) for a more complete review of motion planning techniques for nonholonomic systems.

5.3.3 Control of unmanned air vehicles

Unmanned air vehicles are usually controlled by an autopilot, i.e. a system allowing the UAV to fly autonomously. Nowadays, autopilot systems are automatically implemented in modern aircrafts. The purpose of the UAV autopilot system is to steer the UAV so as to follow either a predefined path or fly between waypoints. Advanced UAV autopilot systems are able to fly the UAV during all flight phases such as take-off, ascent, descent, trajectory following, and landing.

To our best knowledge, all commercially available autopilots are simple PID controllers. It is the best solution for most users as they are simple and require little knowledge to tune on a small UAV. However, PID controllers are also well known in control system theory to lack in optimality and robustness. Researchers have developed several advanced control techniques that can be used in autopilot systems for improved flight performances. We can cite fuzzy logic, neural networks, LQG and $H\infty$ as successful examples of such techniques. Fuzzy logic and neural network techniques are not model-based (knowledge-based for fuzzy logic and data-driven for neural networks) and don't require advanced control knowledge from the user. They represent a good alternative to PID controllers as they usually perform better for multivariable flight control. However, in terms of guaranteed stability and performance, optimal and robust control techniques such as LQG and $H\infty$ sounds more suitable. A combination of Linear Quadratic Gaussian controller and Kalman filter can be used to achieve better altitude control performance. $H\infty$ loop shaping techniques can also be used on small fixed wing UAVs for improvements in noisy or even payload changing circumstances.

5.4 Biomimetic robots

Mobile robotics researchers have been inspired by the trans-disciplinary development in bionics, also known as biomimetics, or biomimicry. Bionics applies biological methods and systems found in nature to the study and design of engineering systems and modern technology. The exceptional natural abilities in many animals and insects have drawn much attention from biorobotists. A common approach is to build animal-like features into robots, and such robots are called biomimentic robots or simply biorobots.

It is debateable whether biologically inspired robotics should be simply emulation of some general feature like legs or wings of an animal, or a more considered approach in which specific structural or functional elements of particular animals is emulated in hardware or software (Delcomyn, 2007). It is difficult to draw a line between the two, although the latter may rely on biological aspect more.

The intensive research effort in searching for hardware and software solutions to emulate specific features of a real animal would expose their efficiency and deficiency, and improve our understanding of those animal features and engineering capabilities and limitations. Whether a design solution comes from engineering or a biological perspective, it is generally agreed that certain degree of fusion and integration between engineering and biology takes place. Despite minute differences in interpretation and emphasis, bionics, biorobotics, biomimetics, or biologically inspired robotics is emerging as a discipline in its own right. It has witnessed an explosion of research interests and efforts in the past few decades worldwide. Researchers working in this field rightfully claim their own identity – biorobotists, or bionicists. It is fitting to recognise that engineers apply biological principles to construct robots, and biorobotics in turn can advance biologists' knowledge and understanding of those same biological principles

Rapidly growing interests in biorobotics were confirmed by the statistics shown in (Delcomyn, 2007). There are more than 1.5 million hits one obtained by conducting a Google search on the phrase "walking robot". In terms of research literature included in the ISI Web of Knowledge database, the number of papers on mobile robotic machines with biological inspiration or variants as a key phrase has increased from an average of 9.2 papers per year between 2000 and 2004, to 16 in 2005 (an increase of over 70%), and 30 in 2006 (another increment of more than 85%). Though not large, this is nevertheless a field that is attracting much attention.

Biorobotics research has covered many types of animals to be emulated - fish and eel underwater; dog, cockroach, gecko on land; and black flies, wasps, bumblebees and other flying insects in air. These robots are built to swim, walk, climb a wall or a cable, or fly. Wall climbing robots have been considered to replace human beings to perform dangerous operations on vertical surfaces like cleaning high-rise buildings, inspecting bridges and structures, or carrying out welding on a tank. The locomotion of a wall climbing robot has become a key research, which is achieved through some kind of attachment mechanism.

Generally speaking, three main types of attachment mechanisms are used: suction, magnetic and dry adhesion mechanisms. The suction method creates vacuum inside cups through vacuum a pump, the cups are pressed against the wall or ceiling so that adhesion force is generated between the cups and the surface. This effect is dependent on a smooth impermeable surface to create enough force to hold the robot.

A wall-climbing robot with a single suction cup has been studied in (Zhao et al., 2004). It consists of three parts: a vacuum pump, a sealing mechanism with an air spring and regulating springs, and a driving mechanism. Two application examples were considered: i) ultrasonic inspection of cylindrical stainless steel nuclear storage tanks, and ii) cleaning high-rise buildings.

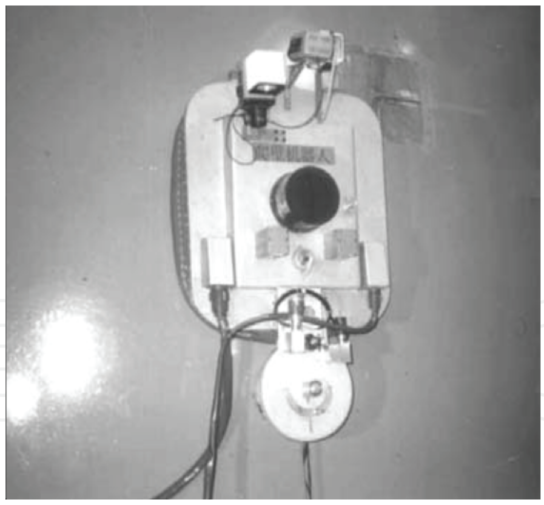

Fig. 14. A wall-climbing robot with a single suction cup

Magnetic adhesion has been implemented in wall climbing robots for specific applications such as nuclear facilities or oil and gas tanks inspection (Shen, 2005). In specific cases where the surface allows, magnetic attachment can be highly desirable for its inherent reliability.

Recently, researchers have developed and applied synthetic fibrillar adhesives to emulate bio-inspired dry adhesion found in Gecko’s foot. An example is Waalbot using synthetic dry adhesives developed by Carnegie Mellon University, shown in Fig. 15. Fibres with spatulae were attached to the feet of the robot, and dry adhesion is achieved between the robot feet and the surface.

Also based on the dry adhesion principles is a bioinspired robot “Stickybot” (Kim et al., 2008). It is claimed that the robot climbs smooth vertical surfaces such as glass (shown in Fig. 16), plastic, and ceramic tile at 4 cm/s. The undersides of Stickybot's toes are covered with arrays of small, angled polymer stalks. In emulating the directional adhesive structures used by geckos, they readily adhere when pulled tangentially from the tips of the toes toward the ankles; when pulled in the opposite direction, they release.

	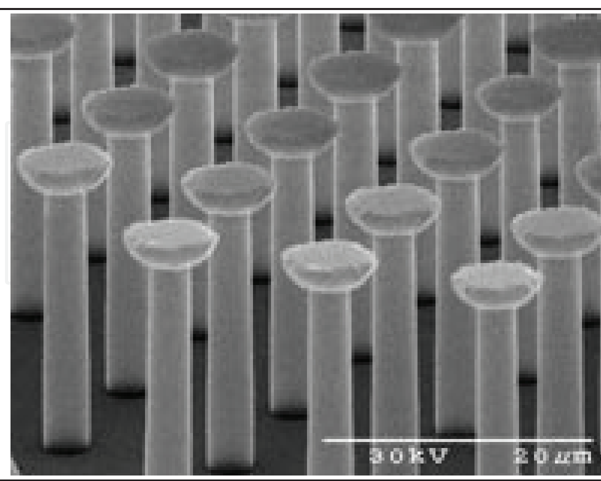
(a) CAD model	(b) Fibres with spatulae to achieve dry adhesion

Fig. 15. Tri-leg Waalbot (http://nanolab.me.cmu.edu/projects/geckohair/)

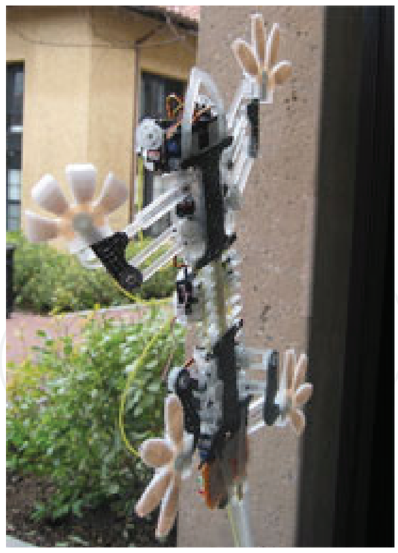

Fig. 16. Stickbot http://bdml.stanford.edu/twiki/bin/view/Main/StickyBot

Existing wall climbing robots are often limited to selected surfaces. Magnetic adhesion only works on ferromagnetic metals. Suction pads may encounter problems on the surface with high permeability. A crack in a wall would cause unreliable functioning of the attachment mechanisms, and cause the robot to fall off the wall. Dry adhesion methods are very sensitive to contaminants on wall surface.

For this reasons, a wall climbing robot independent of wall materials and surface conditions is desirable. The University of Canterbury has develop a novel wall climbing robot which offer reliable adhesion, manoeuvrability, high payload/weight ratio, and adaptability on a variety of wall materials and surface conditions (Wagner et al, 2008). Their approach is based on the Bernoulli Effect which has been applied in lifting device. It is believe that for the first time the Bernoulli pads have been successfully developed as a reliable attachment for wall climbing robots, as shown in Fig. 17.

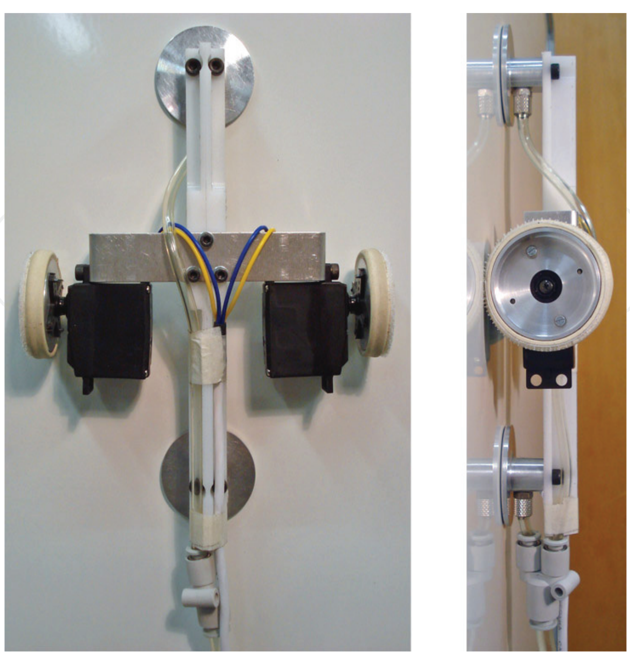

Fig. 17. An innovative wall climbing robot based on Bernoulli Effect.

As a standard Bernoulli device only offers a small attraction force, special attachment mechanisms have to be designed to enhance effectiveness of mechanical force generation. The mechanisms are designed to create the force without any contact to the surface. They literally float on an air cushion close to the wall. The contact between the robot and the wall lies in wheels with tires made of a high friction material which avoids sliding. The non-contact mechanisms provide a continuous and relatively constant suction force as the robot manoeuvres. The locomotion through the motorised wheels ensures smooth motion of the robot, which is paramount for continuous 3D curvature surface operation.
The advantage of the novel approach is that the adhesion force is largely independent of the type of materials and surface conditions. High attraction forces can be achieved on a broad range of surface materials with varying roughness. The experimental results show that the robot weighing 234 grams can carry an additional weight of 12 N, with the force/weight ratio being as high as 5. The device accommodates wall permeability to air to a certain degree, which means that gaps and cracks, which would pose a hazard to conventional suction methods, can be tolerated by the novel device. Furthermore, the robot is easy to setup using a standard pressure supply readily available industry wide.

5.5 State-of-art reported in this book

This book reports current states of some challenging research projects in mobile robotics ranging from land, humanoid, underwater, aerial robots, to rehabilitation. The book also covers some generic technological issues such as optimal sensor-motion scheduling, mobile data collector, augmented virtual presence, and indoor localization techniques. Some of the research works are directly related to demanding task and collaborative missions.
Chapter 2 introduces a field robot using the rotated-claw wheel that has strong capacity of climbing obstacles. The experimental results demonstrate that Rabbit can move in different terrain smoothly and climb over step of 8.1cm and slop of 40°. The Rabbit can adopt different moving modes on different terrains. Because the rotated-claw wheel overcomes the disadvantages of conventional mobile robot wheels, it provides a better solution for field and planetary robots.
Chapter 3 presents a mobile wheeled robot with step climbing capabilities using parallel individual axels. Each axel offset a given radius from the wheel set axis of rotation. In this way, the wheels could revolve and also be powered from a source of angular speed and torque. The wheel sets could also revolve in any direction independent of the rotation of the wheels. This design seemed to satisfy the primary requirements for the robot for both rough terrain and stair climbing.
Chapter 4 reviews some of the main efforts made over the past 20 years in the field of cable-climbing mechanism design to provide a basis for future developments in this field. History of the research in this field shows that due to the huge benefit of early detection of likely damage to the line, even the cable-climbing robots capable of only climbing on part of the line between two obstacles are in use, and further researches in this field will definitely benefit the power companies to efficiently manage their assets. In addition, based on the reviewed works, a flying-climbing platform which is a commercially available UAV modified with a cable-climbing mechanism would enormously benefit the line inspection quality and the design universality.
Chapter 5 proposes a multi-sensing fusion system to mimic the powerful sensing and navigation abilities of a cockroach. It consists of binocular vision system based on infrared

imaging, and tactile sensors using fibre optic sensors and position sensitive detectors. The paper further proposes a distributed multi-CAN bus-mastering system based on FPGA (Field Programmable Gate Array) and ARM (Advanced RISC Machine) microprocessor. The system architecture provides stage treatment for control information and real-time servo control. The control system consists of there core modules: (1) node part of CAN bus servo drive; (2) distributed multi-CAN bus-mastering system composed by FPGA; (3) software system based on ARM and RTAI.

Chapter 6 highlights some characteristics observed from human abilities in performing both knowledge-centric activities and skill-centric activities. Then, the observations related to a human being's body, brain and mind guide the design of a humanoid robot's body, brain and mind. After the discussions of some important considerations of design, the results obtained during the process of designing the LOCH humanoid robot are shown. It is hoped that these results will be inspiring to others.

Chapter 7 reports an AUV prototype that had been developed recently at the University of Canterbury. The AUV was specially designed and prototyped for shallow water tasks, such as inspecting and cleaning sea chests of ships. It features low cost and wide potential use for normal shallow water tasks with a working depth up to 20 m, and a forward/backward speed up to 1.4 m/s. Each part of the AUV is deliberately chosen based on a comparison of readily available low cost options when possible. The prototype has a complete set of components including vehicle hull, propulsion, depth control, sensors and electronics, batteries, and communications. The total cost for a one-off prototype is less than US $10,000. With these elements, a full range of horizontal, vertical and rotational control of the AUV is possible including computer vision sensing.

Chapter 8 establishes an approach to solve the full 3D SLAM problem, applied to an underwater environment. First, a general approach to the 3D SLAM problem was presented, which included the models in 3D case, data association and estimation algorithm. For an underwater mobile robot, a new measurement system was designed for large area's globally-consistent SLAM: buoys for long-range estimation, and camera for short-range estimation and map building. Globally-consistent results could be obtained by a complementary sensor fusion mechanism.

Chapter 9 addresses flight dynamics modelling and method of model validation using on-board instrumentation system. It was found that the aerodynamics coefficients determined by software packages do not accurately represent the actual values. The experimental drag coefficients are higher than those predicted by the software model and this has a large affect on the accuracy of the flight dynamic model. The validation process involves in-flight measure of all parameters as well as wind speed detected by in-house build air-speed sensor. The sensor hardware allowed the collection of flight data which was used to assess the accuracy of the flight dynamics model. The presented validation process and hardware makes a step towards completing an accurate flight simulation system for auto-pilot development and preliminary design of UAVs.

Chapter 10 describes a numerical procedure for optimal sensor-motion scheduling of diffusion systems for parameter estimation. The state of the art problem formulation was presented so as to understand the contribution of the work. The problem was formulated as an optimization problem using the concept of the Fisher information matrix. The work further introduces the optimal actuation framework for parameter identification in distributed parameter systems. The problem was reformulated into an optimal control one.

It solved parameter identification problem in an interlaced manner successfully, and successfully obtained the optimal solutions of all the introduced methods for illustrative examples. It is believed that this work has for the first time laid the rigorous foundation for real-time estimation for a class of cyber-physical systems (CPS).

Chapter 11 presents some heuristics for constructing the mobile collector collection route. The algorithm's performances are shown and their impact on the data collection operation is presented. There are many directions in which this work may be pursued further. Statistical measures are required to measure the buffer filling rate and thus the sensor can send its collection request before its buffer is full, which gives an extra advantage for the mobile collector. Applying multiple mobile collectors can enhance the performance. Control schemes for coordinating multiple collectors need to be designed efficiently to maximize the performance.

Chapter 12 discusses the development of the AR-HRC system from concept and background through the design of the necessary set of interfaces required to enhance human-robot interaction. It has shown that the AR-HRC system does enable natural and effective communication to take place. The use of AR affords the integration of a multi-modal interface combining speech and gesture interaction, as well as providing the means for enhanced situational awareness. The AR-HRC system gives the user the feeling of working in a collaborative human-robot team rather than the feeling of the robot being a tool, as a typical teleoperation interface provides. Therefore, the development of the AR-HRC system brings closer the day when humans and robots can truly interact in a collaborative manner.

Chapter 13 details a set of classifications of indoor localization techniques. The classifications presented in this chapter provide a compact form of overview on WSN-based indoor localizations. The chapter further introduces server-based and range-based localization systems that can be used for the indoor service robot. Specifically, it presents UWB, Wi-Fi, ZigBee, and CSS-based localization systems. Since the methods introduced in this chapter are RSSI-based method, the system is very simple and the implementation cost is much cheaper than TOA and TDOA-based methods, such as Ubisense systems and CSS systems.

Chapter 14 proposes a wearable soft parallel robot for ankle joint rehabilitation after carefully studying the complexities of human ankle joint and its motions. The proposed device is an improvement over existing robots in terms of simplicity, rigidity and payload performance. The proposed device is very light in weight (total weight is less than 2 Kg excluding the weight of support mechanism) and is inexpensive. The kinematic and workspace study is carried out and the performance indices to evaluate the robot design are discussed in detail. It attempts to use an algorithm that maximizes a fitness function using weighted formula approach and at the same time obtain Pareto optimal solutions.

6. Challenges ahead

Despite rapid development of robotics technologies in the past decades, there still exist many technical issues and challenges ahead in realising the full potential of mobile robots. These challenges include standardization, software, hardware and control. In face of ever increasing aging population and human augmented functions, service robots will have significant impact on the society as well as individuals.

6.1 Standards and architecture

In the last century, the manufacturing industry has benefited enormously from the rapid advancement and maturity of computer numerical controlled (CNC) machines. Mechanical parts are automatically produced from a computer model. CNC machines have become a common tool widely accepted by the manufacturers, large or small. The same story cannot be said of robots. Even for a simple task, different robots will have different ways of programming and execution. The lack of standards in robot programming has become a serious limiting factor in promoting robots in the industry. There is a need of a combined effort from the industry, research community and professional bodies to standardise robot programming language. This will be a significant step forward using robots as a common versatile tool that can be easily deployed, mastered and re-programmed.

6.2 Intuitive learning and control

As researchers aspire to create more mobile robots for health care, domestic work, or automating tasks that too dangerous for human beings, the intuitiveness of robots in almost non-existent at present. The industry still feels much more comfortable about hiring a new worker who understands instructions, does a job effectively, and can be easily retrained than employing a mobile robot who is not humane in terms of learning. A human operator learns how to correctly carry out a job through observation and iterative learning by practicing. These processes are simple and intuitive to a human being, but it is still impractical for a mobile robot, indeed any types of robots.

An illustrative example would be polishing of 3D high-pressure turbine (HTP) vanes (Chen 2000a). The manual operation is depicted in Fig. 18. The procedure of the operation is as follows.

Manipulate the part correctly in relation to the tool head, with two-arm coordination.

Exert correct force (up to 15 kg) and compliance between the part and the tool through wrists, and control the force interaction based on process knowledge.

Adapt to part-to-part variations and observe the amount of material removed through visual observation and force feedback.

Check the final dimension with gages.

Repeating step 1 to 5 until the final dimension is achieved. It takes about 10 minutes to finish one piece.

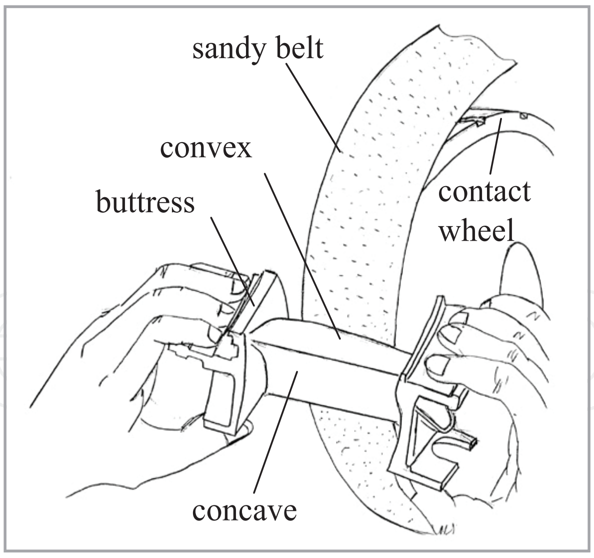

Fig. 18. Manual polishing of aero engine turbine vanes

A robotic system was developed to automate the operation depicted in Fig. 19. The system (Chen, 2000b) has a self-compliant mechanism that grips the part as an operator does with two hands.

In its appearance, the robot does look like an operator in manipulating the part to achieve desired contact states between the workpiece and the polishing tool, remove the right amount of materials through force feedback control. It shortens the cycle time from 10 minutes for manual polishing to an average of 5.75 minutes, resulting in an improvement of 42.5% (Chen, 200b). Such an improvement mainly comes from two advantages that the robot has over a human operator. Firstly the robot can exert a large force constantly while the operator is unable to exert a large force for a long period. Secondly the robot is more deterministic in planning the polishing paths after obtaining the part measurement (which is part of 5.73 minutes cycle time), hence removes the iterations of inspect-then-polish in manual operation and optimises and reduces the number of polishing passes.

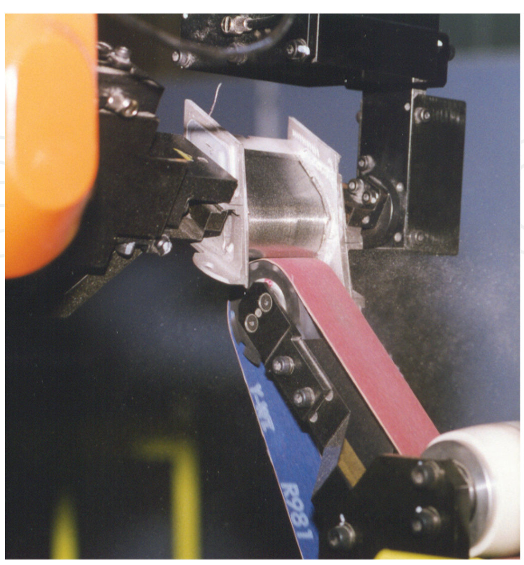

Fig. 19. Robot grips the part with a compliant robot end-effector grips part.

However this system's force regulation during the polishing is still based on simple robot positioning control. To increase or decrease the contact force which is detected by a spring mechanism mounted inside the polishing tool, the robot moves the part in or out in reference to the polishing tool. For a robot to be more adaptable to contact tasks, and intrinsically safe, combined force and visual servoing is highly desired as if the operator exerts a muscular force based on his/her tactile and force sensing intuitively.

As mobile robots make inroad into service and healthcare sectors where physical interactions between robots and human beings take place, controlling robot movement, particularly the movement of motivational parts (legs, feet, arms, fingers), intuitively based force servoing is paramount. From engineering point of view, such intuitive control coupled with flexible and compliant manipulator will enable a robot to execute a contact task, e.g. help a patient lay down or use toilet, more efficiently and safely.

Another important aspect of intuitiveness lies in the way to learn skills and re-apply the skills. Certainly, with the skills learnt, the operator can easily handle other types of parts, and the skills are reusable. If a robot can emulate human intuitiveness, it should be able to take simple instructions, observe the manual operation, practice under supervision, and eventually master the skills to polish a 3D surface. Like a human operator, the robot can take the skills learnt and be readily transferrable to another product line. There is still a long way for robots to gain such intuitiveness.

6.3 Software designs

Software designs rely on a software platform to achieve desired cognition and intelligence.

Practical Robot Software Platforms. Various robot software platforms are already available (e.g. Evolution Robotics). These systems can provide a cost-effective way of producing and operating home-security robots, and will continue to increase in functionalities.

Robot Cognition and Artificial Intelligence. Advances robots with cognitive abilities, artificial intelligence and associated technologies are vital for the development of intelligent, autonomous robots for domestic applications.

In the future, mobile robots will require increased flexibility and robustness to the uncertainties of the environment. Their predicted increased presence in daily life means that they will have more tasks to perform and that these tasks will be diverse. An envisioned approach to fulfil these requirements is to engineer the robots so that some of the processes, inherent to the multiple functions to be performed, can be adapted based on contextual knowledge. In other words, information from the robot's surroundings gathered by multiple sensors could be used to help the robot to achieve its tasks and even determine future tasks. We can imagine a household robot deciding to clean the room when it "feels" that the room is dirty.

Robotics is not the only field of research where contextual knowledge plays an important role. In the literature, five specific tasks stand out as important for future research: Behaviour, Navigation, Localization and Mapping, Perception.

Decision making based on contextual knowledge can easily be foreseen as useful in robotic scenarios, the common scenario being to adapt the robot's behaviour to different situations which the robot may encounter in operation. This is usually dealt with via plan selection, hierarchical approaches to planning and meta-rules.

In the context of motion planning, the goal would be to find general solutions that can easily be adapted in case of a change of context. Typically, however, to obtain effective implementations, specific algorithms and optimal solutions for specific cases are required. The use of contextual knowledge can provide the necessary information to modify a general technique so as to solve the problem at hand. In many cases, the navigation process is included into a more complex process (for example exploration of the environment) where the robot needs to find a target to reach and meet that target. It can easily be envisioned that contextual knowledge can help set priorities when the robot has different missions to fulfil.

Contextual knowledge can also be useful for a robot to map its environment in an abstract manner. Introducing language-based information (for example objects names, colors or shapes) in addition to precise information about the environment can help the decision making process as well as provide improved human-robot interactions. Contextual knowledge may be used for selecting routines. The use of contextual knowledge can be enlarged, for example, to decide when the robot can halt the mapping process and switch to another function.

The use of contextual knowledge has a long tradition in Vision, both from a cognitive perspective, and from an engineering perspective. Indeed, also robot perception can benefit significantly from contextual knowledge. Moreover, it is through the sensing capabilities of the robot that environmental knowledge can be acquired. In robot perception, normally, iterative knowledge processing occurs: a top-down analysis, in which the contribution given by the environmental and mission related knowledge helps the perception of features and objects in the scene; a bottom-up analysis, in which scene understanding increases the environmental knowledge

6.4 Hardware technologies

Affordable robots will continue to be built using fairly conventional hardware—off-the-shelf electronic components, batteries, motors, sensors, and actuators. Materials and designs for statue and motivational parts of the robots have not changed fundamentally, which has been a significant limiting factor in advancing robotics technology and robot performances. Table 2 compares the lifting capacity and lifting-to-weight ratio. For a typical articulated industrial robot weighing 359 Kg, the lifting-to-weight ratio is about 0.03. The well-known Honda humanoid robot lifts 1 Kg with two hands while a person of a similar body mass can lift 20 Kg. Weighting lifting athletes can have lifting-to-weight capacity as high as 2.4. In this regards, the robot construction is very inefficient compared to human build. Novel materials and actuators are a key to building lighter robots for higher handling capacity.

	Self weight (Kg)	Lifting capacity (Kg)	Lifting-to-weight ratio
ABB IRB 2000	350	10	~0.03
Honda Asimo	52	1 (for two hands)	~0.02
2008 Olympic Women 53 Kg Weightlifting Gold	53	126 (clean & jerk)	~2.4
A person having similar weight to Asimo	52	~ 20	~0.4

Table 2. Robot versus human: lifting capacity

Table 3 compares the motion range of robot wrist and human wrist. Generally speaking, robots have better positioning repeatability and consistency than human beings. But human beings accomplish precision tasks through powerful perception and intelligence.

	Human	Robot
Positioning repeatability	~ mm	~ μm
Consistency	Fair	good
Wrist movement (roll, pitch, yaw)	±90°, ± 40°, ± 20°	±200°, ±120°, ±200° (ABB IRB 2000)
Finger flexibility	Dexterous (14 dof)	Primitive
Mobility	Excellent	Poor
Dynamics & compliance	Excellent	Poor
Process knowledge	Excellent	Primitive
Observatory control	Excellent	Primitive

Table 3. Robot versus human: manoeuvrability and Intelligence

Robots generally have larger range of wrist movement. As illustrated in Table 3, the industrial robot ABB IRB200 has ±200°, ±120°, and ±200° movement for roll, pitch and yaw respectively, as opposed to ±90°, ± 40°, and ± 20° for human wrists. However the robot's superiority does not translate to better dexterity. In fact a human operator is much more dexterous in manipulating objects as in the case of polishing 3D surface. This arises from: 1) natural coordination of two hands, and more importantly our fingers, a total of 14 degrees of freedom, are separately actuated. In the case of Asimo, five fingers are driven by the same motor, which can only achieve limited handling dexterity and coordination.

As robots will interact more and more with human, they will need improved mobility and movement capabilities. To achieve human-like movements, robots will have to become much more complex than they are today. The development of these enhanced robots represents an excellent challenge to researchers. However, increasing the complexity of robots' hardware and structure should not be done by neglecting reliability of those same robots. To avoid these problems, the simplification of robots mechatronics will be necessary. Although everyone working on robots acknowledges that, in reality, the design of the mechanical structure greatly affects the performance and controllability, general investigations of the relationship between a robot's mechanical structures and its controllability and reliability have been relatively scarce. This is a fundamental omission in the field of robotics. The research direction would be to find a unified method to create suitable mechanics for autonomous mobile robots that provide good dynamic performance, as well as simplicity and reliability.

6.5 Service robots – a disruptive technology in decades to come

Fig. 20 shows the technology road map of autonomous systems (SRI, 2008). Mobile robots are evolving from unmanned, remote controlled, semi-autonomous, to full autonomous systems. In this evolution, mobile robots require greater mobility, and higher intelligence.

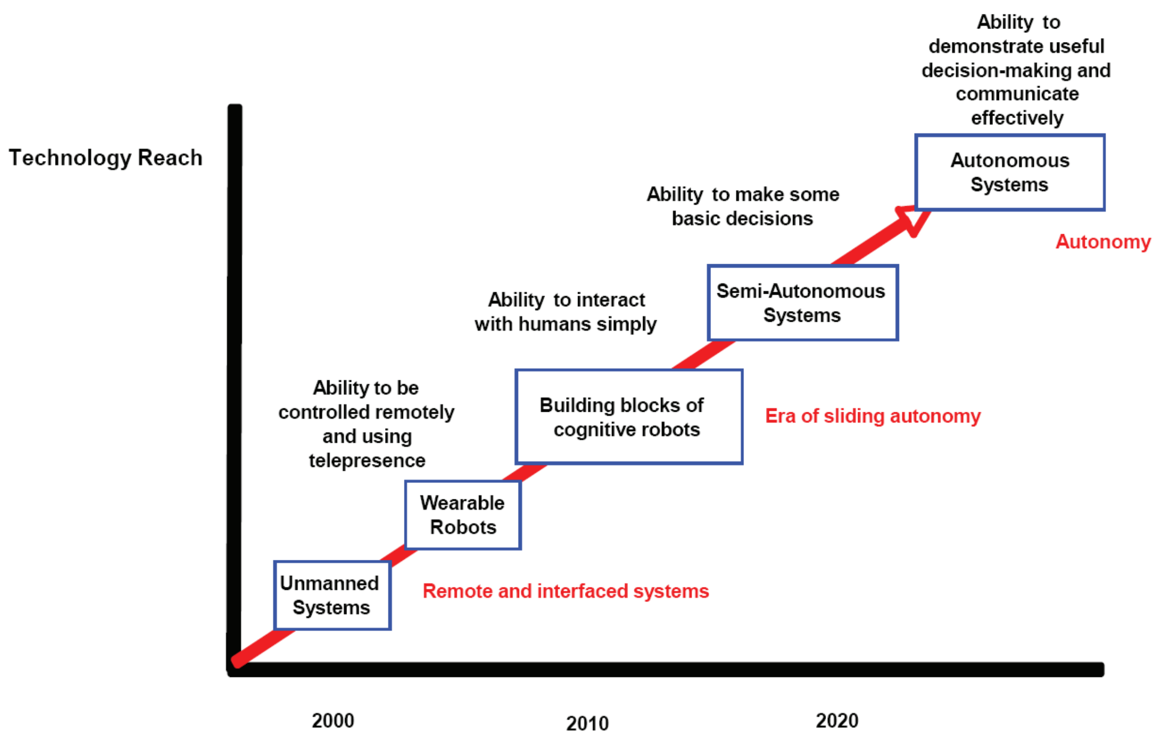

Fig. 20. Technology Roadmap: Service Robotics (SRI, 2008)

The highly integrated systems comprising machines, sensors, computers, and software that have action and reasoning capabilities may relieve human from working in hazardous operations such as welding, plant dismantlement, to operate cutting tools from a safe distance. Robots could offer human-machine interfaces as easy to operate as the current personal computer. Fig. 21 shows a human augmented robotics welding system. It allows the operator to carry out welding remotely.

As the elderly population increases, there are greater and more pressing societal needs of health care and personal assistance at the society and family level. As more people live to the oldest ages, there may also be more who face chronic, limiting illnesses or conditions, such as arthritis, diabetes, osteoporosis, and senile dementia. According to OECD statistics (EURON, 2004), one third to one-half of health spending is for elderly people. Elderly people with varying limiting conditions become dependent on others for help in performing the activities of daily living. These needs call for much faster advancement of service robots that can assist elderly people to perform everyday activities such as bathing, getting around inside the home, and preparing meals.

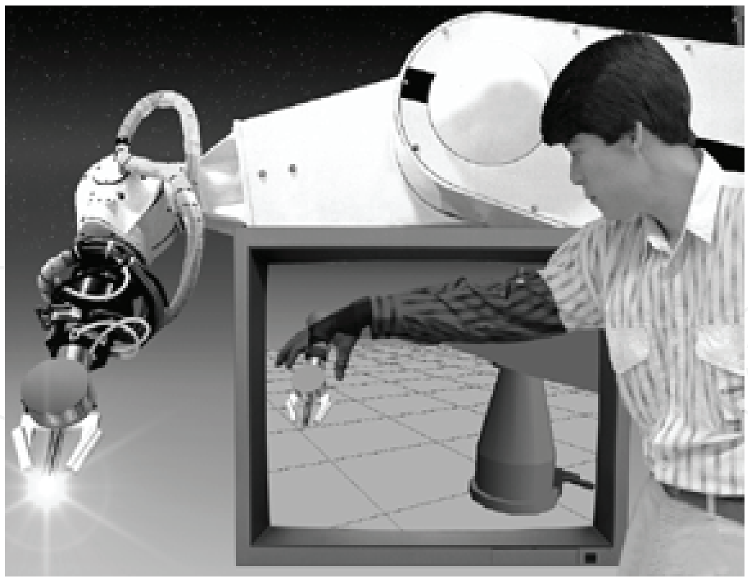

Fig. 21. Human augmented welding robot (http://www.sandia.gov/LabNews/LN03-12-99/robot_story.htm)

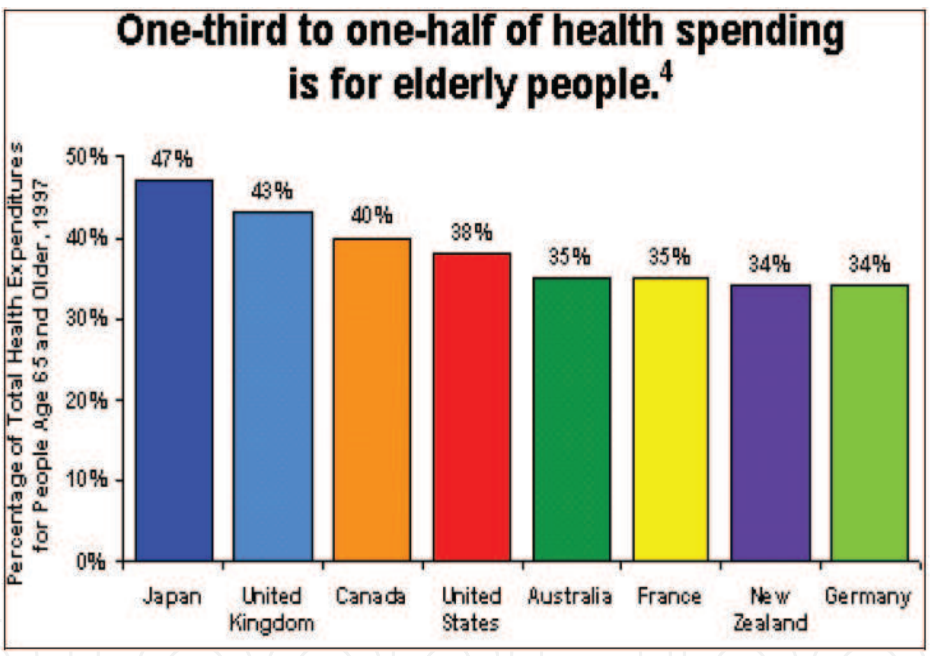

Fig. 22. Health spending quantities (Source: OECD)

According to the IFR (International Federation of Robotics), a service robot is a robot which operates semi or fully autonomously to perform services useful to the well being of humans and equipment, excluding manufacturing operations. Apart from caring for elderly people, service robots will expend into many aspects of the society. A robot nanny may look after children, providing more interactive learning environment (Figure 23.).

Fig. 23. Robot nannies look after children (blog.bioethics.net.)

Robots may replace nurses by performing jobs like dispensing drugs, taking temperatures and cleaning up wards (Figure 24.). The humanoid will make caring for patients cheaper and safer.

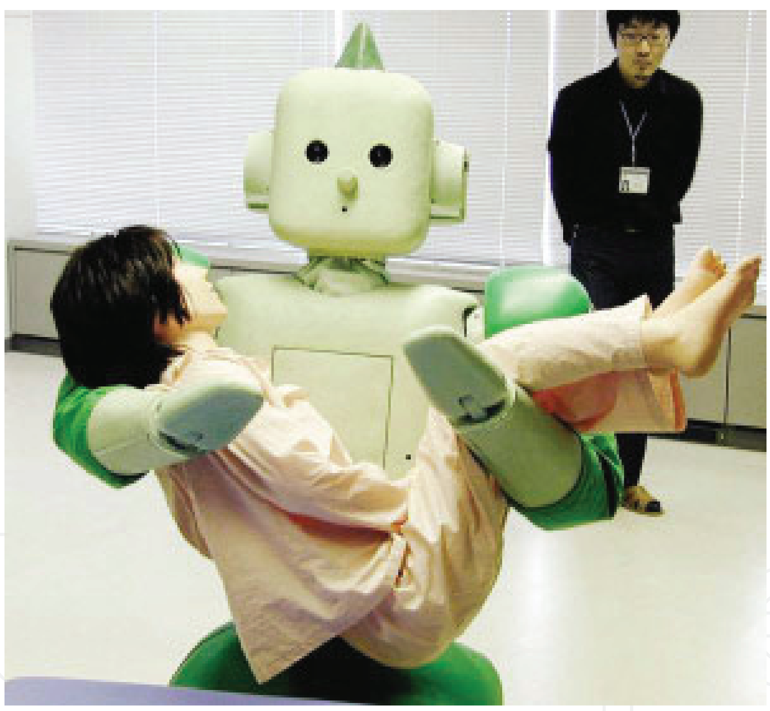

Fig. 24. A robot nurse carries a patient (bp2.blogger.com)

In developing the National Intelligence Council's Global Trends 2025, SRI Consulting Business Intelligence (SRIC-BI) was commission to identify six potentially disruptive civil technologies that could emerge in the coming fifteen years. The six disruptive technologies were identified through a process carried out by technology analysts from SRIC-BI's headquarters in Menlo Park, California, and its European office in Croydon, England. The full finds are published in the recent conference report (SRI, 2008). From 102 potentially disruptive technologies, the following six disruptive technologies have been identified:

Biogerontechnology
Energy Storage Materials
Biofuels and Bio-Based Chemicals
Clean Coal Technologies
Service Robotics
The Internet of Things.

Apart from military applications, the report noted the significant impact of service reports on elder-care applications. It is envisioned that the development of human-augmentation technologies will allow robots to work alongside humans in looking after and rehabilitating people. What is interesting is that some of technologies have dual uses. As opposed to human beings who convert food to energy, robots rely on external power supply. Energy storage, which is also identified as a disruptive technology, has high relevance to service robots as well.

7. Conclusions

Humankind has dreamt of robots being faithful slaves to carry various mundane or intelligent operations since the ancient times. Although there is no universally accepted definition for "robot", the key elements of a "robot" lie in "its ability to perform functions" and "its ability to move". To possess the two basic abilities, a robot requires intellect, actuation, mobility (statue and motivational), sensors, and communication. There is correspondence between robots and human in terms of these functional blocks. Robotics and robot intelligence researchers benefit from understanding of biological systems in developing biologically inspired robots that can emulate the naturally gifted abilities of these subjects.

Mobile robots, as opposed to fix based industrial robots, have huge potential to impact the society. The market for mobile robots is increasing. As such, there has been an explosion of research activities in mobile robots since the emergence of Shakey and Stanford Cart in 1970s. The field has witnessed a variety of attempts to develop mobile robots for critical missions, being on land, underwater or in the air. The applications range from military, to civil and service. Great progress has been achieved in design, perception and control. In terms of bio robots, many techniques have been developed to equip robots with efficient mobility and locomotion. Nevertheless, because of technological limitations, these systems mostly are still confined to laboratory exploitations. The deficiencies in current robotics technology have been key limiting factors in wider acceptance and adoption of mobile robots. Further research and development efforts are required to tackle many challenges and close the gap between proof-of-concept and actualisation.

Wide applications of robots require standardisation and rationalisation of programming languages, system architecture, mechanical/electrical/control interfaces for plug-and-play. The key issues are connectivity, modularity, portability and interchangeability.

The existing robots have limited intuitive learning ability. They have no or little ability to "grow", a natural gift in human. Once programmed to perform one function, robots have little self adaptation to a new function or a variation of the same function. A breakthrough in the theories of intuitive learning and observatory control would make the robots more human-like intellectually, not just physically. This is tied to the ability for a robot to gain contextual knowledge from interacting with environments. Information from the robot's

surroundings gathered by multiple sensors could be used to help the robot to achieve its tasks and even determine future tasks. Furthermore robots grow intellectually so to operate in new environments.
At present, robots are still far more inferior to biological systems in terms of dexterity, coordination, lifting capacity, etc. Hardware technology, such as novel materials, actuation, and mechanical design holds the key to enhance the robot capabilities.
As the society is aging, there are pressing needs for service robots to help elderly people gain greater independence for activities encountered in daily life. In addition to military applications and exploitations, service robots will fulfil different roles in the society, being robot security guard, robot nannies, robot tour guide, robot nurse, etc. In decades to come, they may well emerge as a disruptive technology to impact the society greatly.

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