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white paper

Connected Robots

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Atos

This white paper provides a vision of how robots will develop, increasingly interact with their environment and, through the adoption of new technologies, collaborate, cooperate and evolve.

This paper also shows how IT services providers will play a role in enabling the further development of robotics and how robots will progress beyond the current state-of-the-art into what Atos refers to as the '3i Robot' that embodies information, intelligence and integration.

Connected Robots

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About the Atos Scientific Community

The Atos Scientific Community is a network of some 100 top scientists, representing a mix of all skills and backgrounds, and coming from all geographies where Atos operates. Publicly launched by Thierry Breton, Chairman and CEO of Atos, the establishment of this community highlights the importance of innovation in the dynamic IT services market and the need for a proactive approach to identify and anticipate game changing technologies.

Definition and scope

A simple definition of a robot is: 'any machine programmed to do work'. However, basic machine automation is now so commonplace that this classic definition is being replaced with a more apt phrase – 'a machine with intelligence'. But even this fails to really capture the full essence of what a robot has the potential to be, particularly since the modes of interaction between robots and their physical or virtual environments can be so diverse. The individual and cultural connotations conjured up by the word **robot** could be much, much broader.

Figure 1 outlines the scope of robotic interaction with both the physical and virtual worlds. It considers a range of inputs (both active control and perception driven) and shows examples of the numerous possible outputs, actions or roles that can arise. Using this kind of model, the role of IT services as an enabling and necessary part of the robotic interaction ecosystem begins to emerge.

A robot may have a direct physical manifestation that allows it to mechanically act and react in the real world, but it may also operate in the virtual world using underlying information technologies as a conduit for eventual real-world interaction (e.g. communicate contextual information to remote observers). A robot can also have perception; i.e. it has an ability to assimilate real-world inputs, make 'contextual sense' of them and act according to its programming and what it has learned.

This view of perception, control and interaction serves well, but misses one point that can often be found in the world of science fiction; whether or not a robot can be truly sentient.

In the 1940s, the word robot caught the world's attention when Isaac Asimov coined the Three Laws of Robotics[1]:

- Law 1: A robot may not injure a human being, or through inaction allow a human being to come to harm.
- Law 2: A robot must obey orders given to it by human beings, except where such orders conflict with the first law.
- Law 3: A robot must protect its own existence, as long as such protection does not conflict the first or second law.

Whilst these 'laws' originated within a work of fiction, they nevertheless lay down some potentially important principles to be addressed as robots become more self-aware and are able to act more autonomously, as they will in the future. Fictional writers and moviemakers seem to frequently fuel our vision of the technological future.

Artificial intelligence and miniaturization

In the mid-1900s, laboratories in MIT and Stanford developed various fields of research associated with robotics, including mobility, vision sensing, artificial intelligence and artificial neural networks (machine learning). Technological advances since the first industrial implementations have improved the capability, accuracy and performance of robots, with multiple forms of power actuation now available to suit all environments and functions. Miniaturization has developed to an almost unbelievable level through microprocessor technologies and nanobots can already be built at the atomic scale – potentially powered by electric motors no bigger than a single molecule.

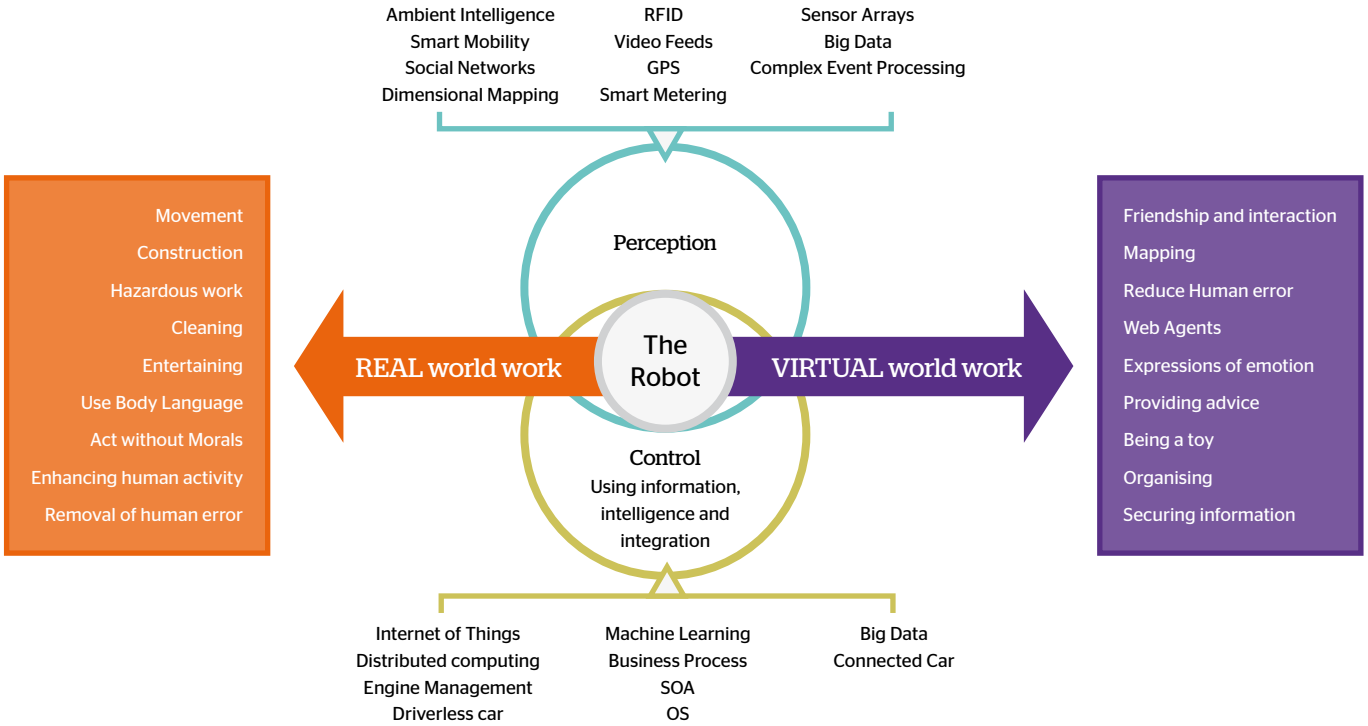

Figure 1 – The scope of robot interactions.

[1] The Asimov rules are introduced in his 1942 short story "Runaround" March 1942, Astounding Science

Insight into the Futuristic Robot

For the most part, robots' 'brains' and control mechanisms currently sit 'on-board' the robots themselves. With advances in IT, especially in wireless communications and virtualization, there is no longer a need for the robotic mind to be confined within its physical body; instead the computational aspects of perception and control can be off-loaded to the Cloud. This could radically alter the way that robots are constructed and operate, and remove some of the constraints they currently face.

Using remote compute resources, the robot will be able to efficiently process and make sense of massive amounts of data within the context of an even wider spectrum of stored knowledge. It will be able to take advantage of acquired learning from other robots, perhaps working within teams or communities. No longer will the robot have to be constructed to protect delicate central processors, instead they can be optimized for the workload they are designed to execute with an emphasis on perception and control rather than processing.

To understand a real-world example of the implications of this approach, this paper considers some of the underlying physics behind a relatively simple form of robot.

The physics of the robot

The following scenario is based on a flying robot that might be used for carrying a camera to perform three-dimensional (3D) mapping tasks in a hazardous environment, perhaps during warfare. One solution is the **quadrotor** which has four separate rotors arranged evenly on a geometric plane. Applying a common change in rotational speed to all rotors allows the quadrotor to rise or fall. Applying combinations of lift and differing rotational speeds to opposing pairs of rotors allows the quadrotor to pitch, yaw and move freely in all three dimensions. However, there is a balance to be struck between agility, size and payload.

In simple terms, the smaller the quadrotor, the lighter and more agile it is, but the less load carrying ability it offers. Unfortunately, there is a disproportionate price to pay with regards to agility when increasing size; for an agile quadrotor, as much un-necessary weight as possible needs to be shed. Off-loading the processing and associated power and storage required for surveillance and mapping to the Cloud, will not only improve the quadrotor's flying characteristics, but will also massively increase its data-processing and interpretation capabilities.

With advances in IT, especially in wireless communications and virtualization, there is no longer a need for the robotic mind to be confined within its physical body.

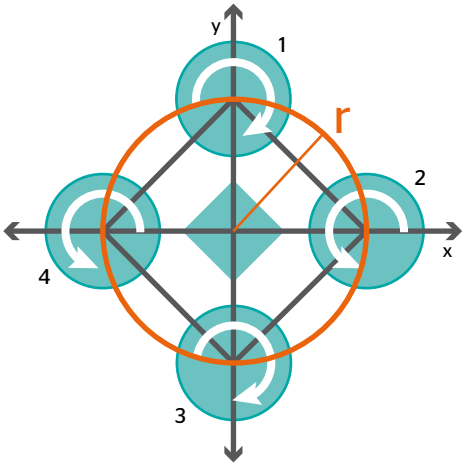

Figure 2 - Diagrammatic representation of a quadrotor.

Where is the Mind of the Future Robot?

Cloud computing is an important enabler for future robotic systems. It will primarily play the role of hosting the **mind of the robot**. Due to the real-time and physical nature of robots, local processing will still be required for the low latency computation necessary for control, but much more compute capability will be available remotely, to support the decision making needed for perception. Consider that the short-term memory of the robot is located in the robot itself, but context and long-term memory are provided by the Cloud. The short-term memory will provide some continued functionality in the case of temporary disconnection with the Cloud.

Advanced artificial intelligence needs massive backend computing power (see Figure 3). The more 'powerful' the robot (in terms of decision making and processing), the more powerful the back office will need to be and the greater the potential to off-load compute-intensive tasks, like image processing, voice recognition, data comparisons and high latency decision making, to the Cloud.

Cloud computing is an important enabler for future robotic systems.

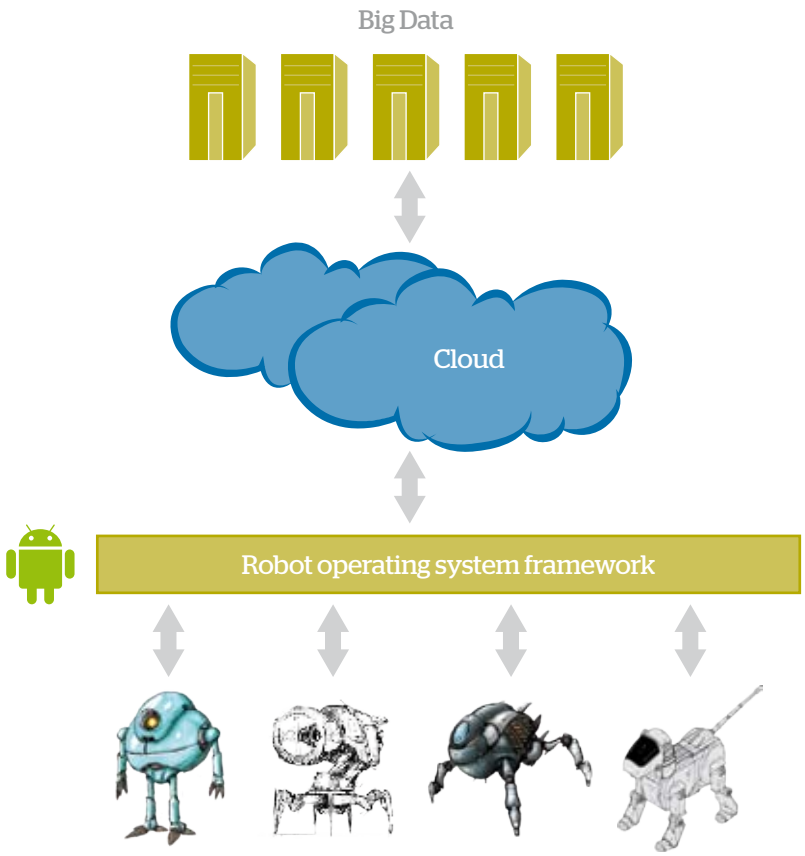

Figure 3 – Cloud computing as the mind of the robot.

Imagine a robot that comes across an object or person that it has never encountered before. With the model proposed above, the robot will send an image of the object or person to the Cloud (where the mind of the robot resides) and the Cloud will send back an identification of the object or person together with advice or instructions on how to respond.

Whilst the processing capability of the Cloud is important, the real differentiator is the ability to integrate the robot's context with the surrounding world and the huge volume of information that can be made available that will complement that coming from the robot's own sensors.

Centralization of processing will also enable multiple robots to be made aware of information and results. This **'hive mind'** will not only be able to process disparate data, but will also be able to store huge amounts of information, securely and in an organized way.

Taking a service-oriented architecture (SOA) approach, certain key robotic functions could be made available as a service on-demand. Just as smart App building blocks have enabled an explosion in widespread smart mobility services, so on-demand robotic functions will drive the creation of more and more advanced robotic processing capability.

One question does arise as to how robots will communicate with the Cloud in the first place. This will require some kind of mediator that sits between the robot and the Cloud.

Robots connecting to the Internet

The Internet will enable the robot's real world to be connected to the virtual world. To give an example: With the emerging robot operating system[2] framework, communication with the Internet via Bluetooth requires only a set of application programming interface (API) calls (see Figure 4).

Future robots will become part of the Internet of Things (IoT)[3] and will be able to seamlessly communicate with the Cloud. These robots will have the potential to use smart mobility and context-aware computing[4] to interact relevantly with their surrounding physical environment.

Using Cloud orchestration[5] and messaging, a robot can also interact with any service, business process or device connected to the Cloud. Communication with the Cloud can be either asynchronous (fire and forget) or synchronous (the robot waits for the response before proceeding with the next action), based on the exposed web services invoked on the Cloud.

Cloud-based messaging will also enable simultaneous patch updates and upgrades within the robot network or on the robot assembly line. Robots might even make use of smartphones as mediators to subscribe to this information via Cloud-based messaging.

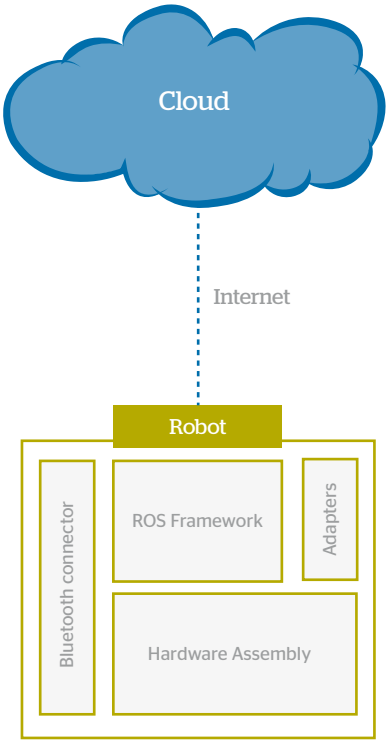

Figure 4 – Schematic model showing robot to Cloud connectivity.

[2] Google has launched the ROS (robot operating system) framework in Java which is Android compatible. The move, coupled with Google's Android Open Accessory API, aims to connect devices like phones, bikes, cameras, and clocks, and at the same time is connected with the Internet world as well.
[3] The Atos Scientific Community has published a white paper on this subject that can be found at: http://atos.net/en-us/about_us/insights-and-innovation/thought-leadership/bin/internet_of_things.htm
[4] Context-Aware Computing is one of the technology disruptions published in Journey 2014 by the Atos Scientific Community which will enable the smartphone to handle events happening in real time.
[5] The Atos Scientific Community has published a white paper on this subject that can be found at: http://atos.net/en-us/about_us/insights-and-innovation/thought-leadership/bin/cloud_orchestration_a_real_business_need.htm

Will the Future Robot mimic human behavior?

The above illustrates how the 'mind' of a robot could be spread across the Cloud. Once connected to the Cloud, there is an opportunity for effective knowledge sharing and robot-to-robot social interaction.

However, security issues such as identity, sensitivity of information and trust are still present. To some extent, the solution to these issues already exists, having been addressed by the social networks used by humans. Atos proposes that high-level robot-to-robot interaction will be facilitated using social networks that are architecturally, metaphorically and perhaps even economically similar to human social networks.

In the same way that biomimicary describes systems that copy the biological world, Atos describes this behavior as 'anthromimicry', i.e. robots or systems achieving tasks in a way that mimics the human world, in a human way. For example, consider how individuals connect to friends on Facebook, in the same way a robot can also connect and communicate with other robots and start accessing, trusting and collaborating with its peers. The 'hive mind' will enable better multi-robot cooperative systems, such as many robots sharing the burden of painting the Golden Gate Bridge, for instance, each knowing which parts have been completed and the most efficient way for them to collectively complete the entire task.

Why limit this to only sharing information with peer robots? Once the robot is part of a social network, it could virtually interact with humans as well, thereby starting to truly mimic human behavior - in the virtual world at least. Using artificial intelligence applications, social networking can be used as a learning behavior input to train a robot (see Figure 5). There are however huge potential pitfalls if such interaction and learning is allowed to occur in an un-moderated fashion. Just as you shouldn't believe everything you read on the Internet, how could a robot know that it is learning the truth? Could robotic behavior be adversely influenced by radical groups?

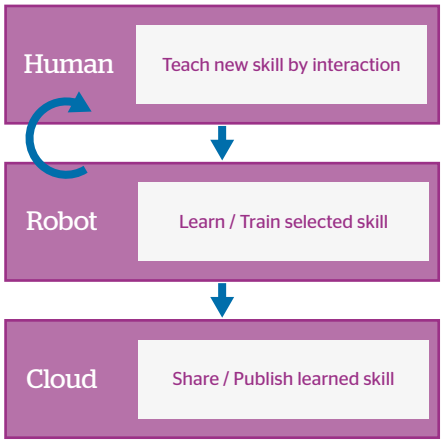

Figure 5 - Learning through social networking.

3i - information, intelligence and integration

Atos has coined the term '3i' which in the context of this white paper refers to information, intelligence and integration. It is the combination of these three areas that will be vital for the next generation of robots and that Atos defines as the characteristics of the 3i Robot that will allow a robot to closely mimic human-like behavior.

The **information** in the 3i model of a robot refers specifically to contextual as well as social network information. To realize Atos' vision of the 3i Robot, any piece of input information (e.g. a measurement device on an industrial robot) will have additional information associated with it; this may include space and time or other sensory data that provides further context to that input. At the same time, there may be elements of social network generated data that may be relevant to and influence subsequent actions.

Once the robot's process controller has the input information, it needs to interpret, visualize or even extrapolate it to allow it to take the right action based on that information. This is where artificial **intelligence** in the Cloud and multi-source information feeds will help robots interpret and decide what action should be taken. 3i Robots will also learn during this process for future reference and to drive predictive responses.

The third 'i' in the 3i Robot represents the **integration** between the physical and virtual worlds. Information needs to flow freely between these environments. It has already been shown that this kind of integration can be made possible using smart mobility and Cloud computing.

Referring back to the original definition, the way that information, intelligence and integration can give rise to the next generation of robots, that Atos calls 3i Robots (see Figure 6), becomes clear. For systems integrators and IT services providers, there are tremendous market opportunities in the fields of Cloud computing, social networking, Internet of Things (IoT) and smart mobility, to name just a few.

Modern state-based architectures such as ADACS™[6] will call on 3i in order to build the future robotic systems which will make use of sophisticated command and control Cloud data centers[7].

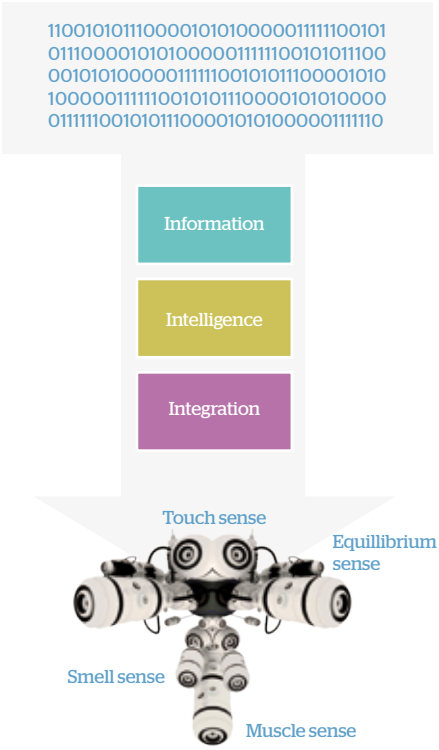

Figure 6 - Atos' vision of the 3i Robot.

[6] Advanced Data Acquisition and Control System
[7] Atos Scientific Community has published white paper on this subject that can be found at: http://atos.net/en-us/about_us/insights-and-innovation/thought-leadership/bin/wp-command-and-control-for-data-centers.htm

Business Opportunities

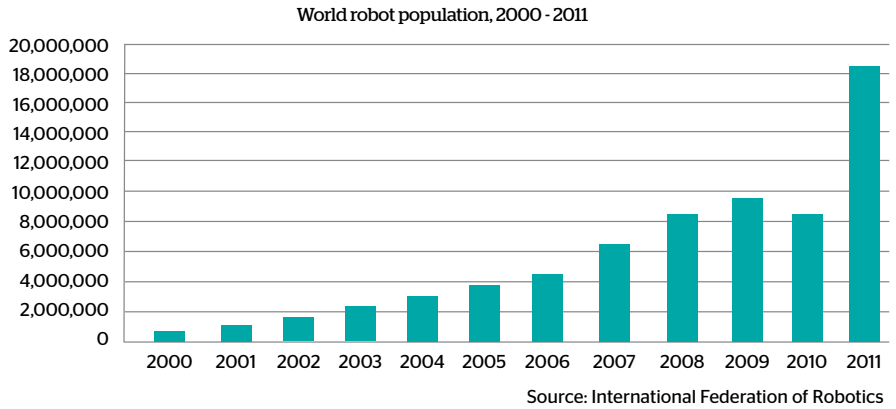

Figure 7 – World robot population.

Looking at robot population trends (see Figure 7), the exponential growth (note the little blip after the credit crunch) cannot be ignored.

The business opportunities for future robots are immense. A few are listed below:

- **Manipulation and physical interaction with the real world:** The future robot will have advanced modeling and control mechanisms that can perform complex actions.
- **Perception for unstructured environments:** Robots will not just be limited to perception in two-dimensional (2D) structured environments. The robot will perceive and interpret 3D environments and take complex actions within the 3D world it is in.
- **Safety for operation near humans:** Personal robots will be fully aware of safety requirements and have control systems to enable operation in the vicinity of humans.
- **Human-robot interaction:** With capabilities to emulate and learn from human behavior, robots will be able to work and interact more closely with humans.
- **Robots collaborating with users, sensors and other robots:** In most current applications, robots operate with a human user or with a collection of sensors in a very structured environment and in a pre-determined manner. With the emergence of networked, embedded systems and the increased presence of collaborative ways of working, robots will soon learn from other robots, from different types of sensors based on contextual information and from different human users.

The future of robotics will span many markets:

- **Transport Systems:** Situational-aware robot vehicles will exist for both public and private transport. Whilst these are now technically possible, they still need to be accepted by society.
- **Industrial Systems:** Robots will further replace human activity in hazardous or complex situations.
- **Intelligent Navigation Systems:** The robot will use and interpret information to maneuver unmanned vehicles, boats and airplanes (unmanned aerial vehicles (UAV)s or drones). It will take autonomous intelligent decisions as the environment is explored.
- **Military Systems:** Existing unmanned vehicles will be complemented by agile armed robots.
- **Security:** An entire security ecosystem can be controlled by 3i Robots; the organizational infrastructure (physical and digital) is controlled by a central security robot that can take real-time actions. The robot checks, correlates and reacts appropriately to attack on physical (environment or premises) or digital assets.
- **Safety Systems:** 3i Robot-based fire protection systems will extend conventional smoke detection sensors with heat, smell, touch and vision capabilities.
- **Medical Industry:** 3i Robot-enhanced medical solutions will enable complex surgical procedures to be safely conducted from thousands of miles away. Sensors and the ability for autonomous control will improve on existing remote-control systems.
- **Energy Industry:** Context-aware sensors and decision-making capabilities will enable 3i Robots to control fuel valves and reactor controls, and make infrastructure repairs.
- **Domestic household applications:** Personal 3i Robots will enable more general purpose activities, replacing the few task-specific robot solutions that exist today[8], fulfilling a variety of household tasks, such a grass cutting, cleaning, home security and bill payment[9] without human intervention.

This concept could sow the seeds for new business opportunities in the field of robotics. For example, intelligent robotic services provided as Software as a Service (SaaS) offerings, an App store for robots or even a robot 'jobserve' so that a robot (or its owner) can find iself a job.

A United Nations Economic Commission (UNEC) report[10] predicts over $50bil. of robot sales by 2025 (see Figure 8).

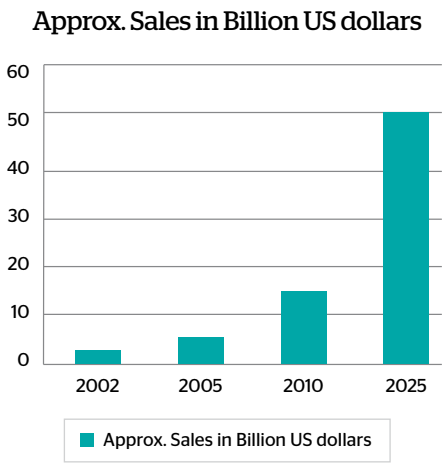

Figure 8 – Approx. sales projection for personal and service robots by UNEC.

[8] Such as the iRobot Roomba vacuum cleaner.
[9] For instance, by scanning received letters and making appropriate automated electronic payments.
[10] http://www.robotinvestments.com/RI_worldwide_market.htm

Issues and Challenges

While robotics will provide a huge number of opportunities in the coming years with many new services appearing in all sectors, service providers need to carefully consider the implications of enabling robotic-based services.

Technological

The introduction of the Cloud will require technical solutions to address latency issues between robot and the hive mind, and the lack of access to long-term memory during network outages.

Security

As the concept of a Cloud-based brain to support robots develops, how each robot will securely connect to the brain and assert its identity must be considered. The risks of emulation, information leakage, sabotage and even terrorism need to be addressed.

Legal and moral issues

Just as Asimov later added his zero'th law, this paper considers the statement it makes: "A robot may not harm humanity, or, by inaction, allow humanity to come to harm".

In the classic ethical trolley test[11], how would society hold a robot responsible for life-impacting decisions, such as throwing the switch on a life-support machine (to give a medical example)?

The same dilemma may be found in every-day scenarios; in the event of a fatal crash, given the increasing number of robotic cars that will be found on our roads, should responsibility be assigned to the passenger for permitting excessive speed (they were in a rush); the robot for taking a decision that costs the lives of others (but saves its own passenger); the manufacturer; or the programmer that set the decision rules?

Effects on society

The introduction of robots and robotic systems is making companies, human beings and society at large, more dependent upon them. This could bring new risks with it, in the same way that society is now dependent on large-scale power, and financial and utility infrastructures. The development of future emergency systems that ensure continuity for robots must therefore be considered.

If a robot cleaner offers a cost-effective way to clean houses, what happens to the people who used to be cleaners? There won't be a shortage of people in the future, so are robots really required to do jobs which humans can do. Atos has penned a potential fourth law – "a robot cannot be allowed to do anything that a person can (safely) do". Trade unions will likely push for this law.

Artificial Intelligence is becoming increasingly sophisticated and robots will enter more households. This could have negative effects on human family systems. There is already less social interaction within families due to games consoles and other handheld electronic devices. The more that users interact with household robots, the higher the risk that the family social fabric will be further impacted.

[11] See http://en.wikipedia.org/wiki/Trolley_problem

Conclusion

Many facets of what was merely science fiction over the past half-century, are now becoming science fact. Technology has advanced to enable robots to interact with their surroundings and cooperate with each other.

There are some limited and specialist examples where information, intelligence and integration have been deployed together[12] to deliver what will become the next-generation 3i Robot.

One area that this paper only briefly touched upon, was the continued miniaturization of robots. At the extreme, nanorobots on the molecular scale are an active area of research and development that will generate interesting new robotic capabilities.

The definitions applied to the term robot could cover an ever-increasing scope of application, as automation and 'intelligence' become more and more pervasive in everyday technology. Whilst the term robot is generally linked to automated, physical, mechanical devices, the 3i definition could also quite naturally be applied to processes in the virtual world.

IT systems' capacity to assimilate data and act on input triggers far exceeds human abilities - the question is whether this is a good or a dangerous thing. Feedback loops within the control systems of robotic financial trading systems could cause the kind of dramatic market fluctuations that are only too common in today's financial markets. Do such levels of virtual automation offer more control or will we be left to deal with the consequences of decisions that have to some extent been taken out of our hands?

As the world becomes ever more interconnected, managing the world of virtual automation will become ever more critical. This is already being seen in areas such as smart energy grid-control systems, where split second decisions have to be made to engage or disengage a myriad of sometimes unpredictable power sources to maintain an overall stable electricity supply - a true convergence of the virtual and physical 'robotic' worlds.

It is this convergence of worlds that presents the real challenge for systems integrators. How can real-time control information be combined with acquired business intelligence and operating rules to safely, reliably and effectively integrate multiple physical, automated entities, to enable their collective operation as a coherent ecosystem?

There is not only an opportunity for systems integrators to participate in the next evolution of robots; the robotics industry absolutely needs their involvement in order to achieve it.

As the world becomes ever more interconnected, managing the world of virtual automation will become ever more critical.

[12] Google's self-driving car is one example

About Atos

Atos is an international information technology services company with annual 2011 pro forma revenues of EUR 8.6 billion and 74,000 employees in 42 countries at the end of September 2011. Serving a global client base, it delivers hi-tech transactional services, consulting and technology services, systems integration and managed services. With its deep technology expertise and industry knowledge, it works with clients across the following market sectors: Manufacturing, Retail, Services; Public, Health & Transport; Financial Services; Telecoms, Media & Technology; Energy & Utilities.

Atos is focused on business technology that powers progress and helps organizations to create their firm of the future. It is the Worldwide Information Technology Partner for the Olympic Games and is quoted on the Paris Eurolist Market. Atos operates under the brands Atos, Atos Consulting and Technology Services, Atos Worldline and Atos Worldgrid.