Plug-and-Play Robotics

Magnus Jändel
Division of Information Systems
Swedish Defence Research Agency
SWEDEN

magnus.jaendel@foi.se

ABSTRACT

The robotics revolution will be the next great industrial transformation where information technology extends into the physical domain. The ramifications of this are enormous both for society at large and for military affairs. Progress in robotics is, however, hampered by the lack of integrating standards. A plug-and-play standard for robotics would catalyze dramatic growth by transforming the structure of the industry from vertical integration to horizontal integration analogous to the personal computer revolution of the early 1980s. This paper offers an historical perspective on standards as catalysers of industrial transformations describes the leading emerging standards in robotics and discusses the consequences of establishing a global standard for plug-and-play robotics.

1.0 THE ROBOTICS TRANSFORMATION

Robotics will eventually utterly transform military affairs. Autonomous missiles have a long history and robots are increasingly used for surveillance, auxiliary tasks and armed combat (usually controlled by human operators). From a technical point of view, existing and emerging robot technologies have the potential for rapidly replacing manned platforms with superior autonomous systems in all arenas. Yet, we are still in the early days of the robotics revolution.

One of the main hurdles of the robotics transformation is the lack of integrative standards for robotics. A global standard for plug-and-play robotics would be instrumental for transforming the structure of the industry and dramatically reduce costs thus facilitating the application of robotics to all domains of modern society. Establishing a standard could be the starting point of a dramatic expansion of the robotics industry and market. The power or combination of powers that first succeeds in establishing a plug-and-play standard encompassing a sufficiently large industrial basis would surge far ahead of competitors. Leadership in robotics would quickly translate to tangible economic and military advantages. A plug-and-play standard for robotics is a truly disruptive technology.

To exemplify the application of plug-and-play robotics consider a military task force wishing to deploy robotic scouts for operations in mountainous terrain. Ideally, commanders should be able to ask a provider to quickly assemble customized units from off-the-shelf parts. The integrator would select a six-legged locomotion module from manufacturer A, a communication module from manufacturer B, a power system from manufacturer C, weapons from manufacturer D, sensors from multiple manufactures and a robot operating system from any of a host of providers. As the hardware and software modules are connected to the system they would automatically be integrated in the plug-and-play fashion that we are used to expect from computer components, software and peripherals. The main work of the provider would be to verify that the pre-tested modules are integrated correctly and perhaps to assist war fighters in configuring the on-board AI for the relevant mission profiles. The cost of the hexapod robot scout would be far lower than present expectations since multiple companies compete for providing parts that are produced in large volumes for a bourgeoning international and mostly civilian market. A plug-and-play standard for robotics would in summary make the robot market of tomorrow operate like the computer market of today in which relevant hardware and software quickly can be assembled for solving the task at hand. Military users would in particular benefit from that components can be replaced in the field and that the same modules can be used in multiple systems.

In section 2 we delve further into catalysing role of standards using the personal computer industry as an example to be contrasted to the present state of the robotics industry. Section 3 describes the scattered landscape of emerging plug-and-play standards for robotics. Conclusions on the present standardization efforts, the way forward and the risks and benefits of the robotics revolution are offered in the last section.

2.0 STANDARDS AS CATALYSERS

The right kind of technical standards may catalyse industrial transformations with paramount consequences for society, life style and economic growth. Major examples in recent times are personal computing and telecommunications. The critical standards can be de facto standards as common in the computer industry or de jure standards as predominantly in telecommunications. The effect of such disruptive standardization is to replace vertical integration with horizontal integration. Vertical integration means that a single vendor develops the total product that is offered to customers e.g. as Boeing develops aircraft for airline operators. This makes for slow development, expensive products and consumer lock-in. Horizontal integration means that a vendor produces large amounts of similar components that via standardized interfaces can be combined into many different end-user products. End-user products consist of many commoditized components. A personal computer includes e.g. operating system, motherboard, graphics card, keyboard and hard drive. All these components are produced by many manufacturers with little qualitative differentiation and are easily integrated to a complete system by an integrator company or even a consumer. Horizontal integration leads often to rapid development of inexpensive mass-market products and consumer empowerment. The transition of an industry from vertical integration to horizontal integration is therefore also often a shift from linear growth to exponential growth. A prerequisite for the emergence of a horizontally integrated market is a foundation of components, prototypes and proof-of-concepts. The transition is catalysed by the emergence of de jure or de facto standards that enable sufficiently easy integration of total products that satisfy pent up demands. In this section we study an example of this kind of transition and examine the present status of the robot industry with respect to standardization.

2.1 The Personal Computer Transition

Many components and functions of what we now recognize as a personal computer (PC) were in place in 1980. The Commodore PET had a screen, keyboard and a tape recorder for data storage integrated in a single unit [1]. Other vendors had similar products. Yet sales and consumer acceptance were slow. A worldwide total of 724,000 personal computers were shipped by about two dozen companies 1980 [2]. The turning point for the personal computer was when IBM 1981 released an open PC architecture that quickly became the de facto standard. A few years later a host of firms shipped IBM PC clones largely built from third-party components. PC worldwide shipments reached 280 million units in 2009 [3]. Almost half of the homes in highly developed countries have a PC.

The key driver for the rapid PC market penetration was the inadvertent establishment of a de facto standard for hardware and software. Personal computing was before 1981 a jungle of mutually incompatible products where core hardware, peripherals and software largely were specific for each platform. Software applications had to be crafted specifically for each platform. Few applications were hence available. All this changed when the industry leader IBM rushed to launch a PC and cut some corners in the development process by using an open hard-ware architecture and an operating system that also was available to competitors. Soon many competing products implemented the PC architecture that would become a de facto standard. A new software industry thrived on the expanding market for IBM PC compatible programs and transformed the PC to a ubiquitous and genuinely useful tool for work, communication and entertainment. Standardization also enabled a burgeoning industry of computer peripherals for gaming, communication, printing and many other purposes. In spite of the rapid increase in performance, ease-of-use and applications the cost of owning a PC actually decreased.

From a consumer point of view standardization is noticeable as plug-and-play performance meaning that a new piece of software and hardware works with little or no configuration once it is installed. Because of plug-and-play integration even consumers lacking specialized knowledge and training can build a PC in a few hours – feat that would have been impossible without a standard. Military forces use PCs for many different tasks and benefit also from the reduced cost of information processing that ultimately is due to the personal computing revolution. To appreciate the power of standards-driven horizontal integration, consider how expensive a modern PC would be if hardware, operating system and applications had been developed by a military contractor according to the vertically integrated business model.

2.2 Robotics

The robotics industry of today resembles the computer industry before the 1980s. Multiple providers of vertically integrated systems offer incompatible and expensive problem-specific solutions. Architecture and interfaces are often closely guarded secrets. Any modularization applies typically only to the present provider's portfolio. Customers suffer from systems that are hard to maintain and expand because of technical lock-ins. There are about 30 providers of industry robots but no integrating standard. The need for standardization is equally obvious for military, service and entertainment robots.

Yet there are no fundamental technical reasons for not implementing a generic plug-and-play standard for robotics. Robots are similar to computers in that they include sensors (input devices), actuators (output devices), information storage and processors. Robot sensors overlap partly with computer and game console sensors but are more diverse with e.g. radar, ultrasound and tactile sensors. Robot actuators are also more diverse with complex arms for industry assembly robots, many types of locomotion for mobile robots and weapons for combat robots. Computer sensors and actuators are, however, also increasingly diverse and there is nothing in the broader span of robotic output and input devices that fundamentally prevents the application of plug-and-play technology. Robots must handle real-time operations but real-time operating systems and real-time applications are common also for computers and provide no insurmountable barrier against standardization.

The need for standards in robotics has often been pointed out by experts [4] [5]. So why is the robotics industry locked in a horizontal integration state that obviously hampers growth? One reason may be that the robotics industry, until recently, mainly catered to corporate customers that willingly pay premium prices for industrial robots that replace even more expensive human labour. The computer industry transition occurred when consumers and small businesses became an important market. In robotics we have just recently seen a rise of consumer service robots (e.g. vacuum cleaners) and entertainment robots that might herald that the robotics business is close to a similar transition point as the computer industry in the beginning of the 1980s. Secondly it might have been an accidental circumstance that an industry leader launched open PC architecture at the right moment. Robotics lacks a dominating industrial player that can enforce a de facto standard.

3.0 EMERGING STANDARDS IN ROBOTICS

There are many types of standards that are relevant for robotics. The International Organization for Standardization (ISO) provides e.g. a. safety standard for robots in industrial environments [6] and the NATO Standardization agency supplies standards for UAV airworthiness (STANAG 4671) [7]. This section will, however, focus on representative standardization initiatives that address the key issue of plug-and-play integration of robots. For the sake of brevity we overlook several important standardization and code reuse efforts including the Carnegie Mellon Robot Navigation Toolkit (CARMEN) [8] and the open-source project Player [9]. The seven emerging standards discussed in this section include major open-source projects, corporate initiatives, broad industrial collaborations and initiatives from the defence sector.

The Robot Operating System (ROS) [10] is an open-source framework for mobile robots. ROS emerged 2007 from a Stanford research framework and the driving force is California-based robotics start-up Willow Garage supported by more than twenty partners. ROS includes a peer-to-peer communication system connecting multiple heterogeneous nodes and processes and means for discovering and using services provided by processors, sensors and actuators. An expandable library of packages for relevant functions such as motion tracking, planning, locomotion and grasping ensures a continuous growth of functions. The main thrust is on UNIX-based systems but a broader support of other platforms is in the pipeline. There seems to be a considerable momentum for ROS in the open-source and academic communities and a recent review of U.S. robotics mentions ROS as the most promising emerging standard [4].

Orca is an open-source framework aiming at promoting re-use of robotics software [11]. It is agnostic of programming language, operating system and architecture. The Internet Communications Engine (ICE) [12] is used as a communications layer, for setting up a registry for service discovery and for managing components. Full Linux and partial Windows and MacOS support are available. The followers are mostly academic but include a few industrial users. The architecture independence and the policy of maximizing cross-platform interoperability at the expense of efficiency makes Orca more of a managed library of re-usable software components and less of a plug-and-play standard.

Sony has since 1997 touted OPEN-R as a standard for entertainment robotics [13]. OPEN-R is a centralized layered architecture where each component carries data describing its function, status and interfaces. Components register automatically with the central CPU thus allowing the robot to discover the present sensor, actuator and software configuration. Sony has since the launch vacillated between openness and protectiveness. This and the basically proprietary nature of OPEN-R have barred any wider industrial adoption.

The Microsoft Robotics Developer Studio (MRDS) [14] facilitates writing programs that concurrently handles multiple sensors and actuators in real-time. MRDS includes a visual programming environment and simulation tools for testing and visualization. Developed programs can be uploaded to robots provided that they run on-board Microsoft operating systems such as Windows CE. Means for hard-ware integration are not provided. This and the limited choice of operating systems discourage industry-wide adoption. The programming and simulation tools are the main benefits and MRDS are therefore presently mainly used for research and by hobbyists. MRDS could, however, be a forerunner of a Microsoft-based generic robotics platform.

The Object Management Group (OMG) develops enterprise integration standards including the Unified Modelling Language (UML) and the Model-Driven Architecture (MDA). The over 800 members include, Hewlett-Packard, IBM, Lockheed Martin, Microsoft, Nortrop Grumman, THALES and Unisys. The Robotics Domain Task Force (DTF) of OMG aims at extending OMG standards to robotics including both software and hardware and to increase interoperability in robotics by collaborating with other standardization organizations. The OMG program is supported by leading Asian players such as the Japan Robot Association (JARA) and The (Japanese) National Institute of Advanced Industrial Science and Technology (AIST). AIST has developed an open implementation of the OMG specifications [15]. The OMG Robotic Technology Component Specification describes a component model consisting of a platform-independent part and several platform-specific models. The platform-specific models include a model where components communicate directly and a distributed model employing CORBA-based middleware. DTF develops presently a standard for dynamic deployment and configuration of robotic technology components that will bring it even closer to the plug-and-play objective.

Space Plug-and-Play Avionics (SPA) is a set of standards primarily intended for rapid integration of satellites [16]. SPA is developed by the U.S. Air Force Research Laboratory and has been proposed for standardization to the American Institute for Aeronautics and Astronautics (AIAA). Each component in an SPA system includes a data sheet (xTEDS) containing a description of all commands that can be handled and all messages that can be produced by the component. The xTEDS is essentially a machine-readable manual for using the component. The components are connected with data transport means selected from a standardized set of specifications that includes the Universal Serial Bus (USB). A new component (e.g. a radar sensor) that is connected to a SPA system is automatically recognized by the other modules. An on-board processor could read the xTEDS of the new component, send commands to the sensor and subscribe to data generated by the sensor. The ontology supporting interpretation of component data sheets is presently limited to satellites but could be generalized to robotics. The SPA specifications are freely available with the exception of the ontology (Common Data Dictionary) that is needed for writing and interpreting xTEDS. Participation in standard development is, however, restricted to U.S. organizations and a few international partners working under bi-lateral agreements. From a technical point of view SPA has the potential to expand to a generic plug-and-play standard for robotics. Satellites include sensors, actuators, locomotion, navigation, on-board computing, energy management and communication just as advanced mobile robots. A broader ontology is needed and possibly an expanded set of communication specifications. The main hurdle is the restricted set of participants and the limited scope of the present effort.

The Joint Architecture for Unmanned Systems (JAUS) [17] was initiated by the U.S. Department of Defense and is presently developed by the Society of Automotive Engineers (SAE). JAUS takes a top-down service-oriented approach and covers presently two different levels of integration. The highest level specifies communication protocols between system components such as unmanned vehicles, payload and command and control systems. The second level handles interoperability between major subsystems of a mobile robot where each subsystem is understood to be a processing platform e.g. locomotion, sensor array and planning module. JAUS does not specify anything about architecture or implementation but is essentially a message-based protocol. Many extensions including human-machine interfaces and manipulation services are drafted. JAUS has a large footprint in U.S. and NATO military robotics but is not applied extensively in other industrial or in academic contexts.

4.0 CONCLUSIONS

From this brief review of current standardization initiatives it is obvious that the robotics community is well aware of the need for standardization and that many relevant efforts are in progress. There is, however, no leading candidate for a global plug-and-play standard. No industrial player is in the position of establishing a de facto standard as IBM once did for the PC market. Sony is too proprietary and Microsoft has at best a partial solution. Open source groups like ROS and Orca cater mostly to academics and fail to attract substantial groups of industrial users. OMG´s Robotic Domain Taskforce and Space Plug-and-Play Avionics are both focused on component-level interoperability. The former is more abstract and address the global robotics industry including major players in Asia while the latter is technically more specific but limited to satellites and avionics. JAUS focuses on system-level integration and impacts mainly on U.S. and NATO military robotics.

Several of the emerging standards could be merged to form a more complete and powerful option. The JAUS high-level approach could be combined with the component and hardware oriented Space Plug-and-Play Avionics. Alternatively JAUS could be united with the OMG standards as suggested in [18].

Few computer scientists would claim that the IBM PC-architecture is optimal or even was the best option at the onset of the PC-revolution. Yet it transformed the industry and changed society with consequences that still reverberates. Similarly we should note that a plug-and-play robotics standard does not need to be technically optimal or respect all particular interests and opinions. Many divergent forces resist standardization. Robot manufactures that are organized according to the vertical business model guard proprietary technologies. Academics are prone to prioritize technical optimization and will find faults in any proposed standard. Different industrial segments including space, defence, service, industrial and entertainment robotics have different requirements and traditions and there will always be arguments for specialization and adaption to the idiosyncrasies of the segment. Yet all parties would benefit enormously from a common standard. A strong integrative force such as government initiative might be needed for overcoming the diverging forces and catalysing a global standard spanning all relevant domains.

Establishing a robotics standard would not remove the need for hand-crafting military systems. For computers there is a segment for hardware and software that fulfils special military requirements of security, reliability, robustness and electromagnetic compatibility. Similar concerns will extend to robot components and systems. Antennas and other electromagnetic emitters must be integrated with care and knowledge because of electromagnetic compatibility issues. Flying and sea-going robots must comply with aerodynamic and hydrodynamic constraints. In spite of these and similar concerns it is obvious that a robotics plug-and-play standard would be instrumental for reducing cost and development time for advanced autonomous military systems.

Military robots are presently mainly operator-controlled and used for surveillance, de-mining and for combat in low-intensity conflicts. Driven by a rapid evolution of generic robot technology military robots will be increasingly autonomous, capable, affordable and available. This could well trigger an arms race and destabilize the present world order by enabling an unpredictable development and spread of innovative military technology. Aggressive second and third tier powers could, as demonstrated by plentiful historical examples, lead the march into the new era. The robotics transition in military affairs appears to be inevitable but perilous and could increase the risk of armed conflicts. Ethical concerns related to the new technology are also significant [19].

5.0 REFERENCES

[1] Commodore PET, SuperPET, 4040 and 8050 FAQ. Commodore Magazine August (1982).

[2] TIME (quoting Dataquest) December 26 (1982).

[3] Worldwide PC Market, eTForecasts (2010) (see http://www.etforecasts.com/products/ES_pcww1203.htm#1.0).

[4] Hollerbach, J.M., Mason, M.T. and Christenssen; H.I (Eds). A Roadmap for US Robotics – From Internet to Robotics. Workshop on emerging technologies and trends (2009).

[5] Bekey, G.A.; Autonomous Robots. MIT Press, London (2005).

[6] ISO standard 10218-1:2006, Robots for industrial environments – Safety requirements – Part 1:Robot (2006) (available from http://www.iso.org).

[7] STANAG 4671 – Unmanned aerial vehicles systems airworthiness requirements 82009). (available from http://nsa.nato.int/nsa/NSDDPubl/_CommonList.html).

[8] Montemerlo, M., Roy, N., and Thrun, S.; Perspectives on standardization in mobile robot programming: The Carnegie Mellon navigation (CARMEN) toolkit. Proc. IEEE/RSJ Int. conf. on intelligent robots and systems 2436–2441 (2003).

[9] Vaughan, R.T., Gerkey, B.P. and Howard, A.; On device abstractions for portable, reusable robot code. Proc. IEEE/RSJ Int. conf. on intelligent robots and systems 2421–2427 (2003).

[10] Quigley, M., Gerkey, B., Conley, K., Faust, J., Foote, T., Leibs, J., Berger, E., Wheeler, R., Ng, A.; ROS: an open-source robot operating system. Workshop on open source software in robotics (2009).

[11] Makarenko, A., Brooks, A. and Kaupp, T.; Orca: Components for robotics, Proc. IEEE/RSJ international conference on intelligent robots and systems (2006).

[12] Henning, M. and Spruiell, M.; Distributed Programming with Ice. (2006) (Available at: http://www.zeroc.com/ice.html).

[13] Fujita, M. and Kageyama, K.; An open architecture for robot entertainment. Proc. first int. conf. on autonomous agents, ACM Press (1997).

[14] http://www.microsoft.com/robotics/

[15] See AIST press release at http://www.aist.go.jp/aist_e/latest_research/2010/20100210/20100210.html (2010).

[16] Lyke, J., Fronterhouse, D., Cannon, S., Lanza, D. and Wheaton, B.; Space Plug-and-Play Avionics. Proc. 3rd Responsive Space Conference (2005).

[17] http://www.sae.org/servlets/works/committeeHome.do?comtID=TEAAS4 .

[18] Rioux, L. and Robinson, C.R.; A standards based architecture using JAUS and RTC. Proc of int. conf. on simulation, modelling and programming for autonomous robots (2010).

[19] Lin, P., Bekey, G. and Abney, K.; Autonomous Military Robotics: Risk, Ethics, and Design. Philosophy 1-112 (2008).