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Modularity in Service Robotics

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1. Introduction

Versatile service robots are highly complicated systems. A breakthrough of a mobile service robot market requires substantial advancement in the standardization of the modules used in their structures.

At the moment, extensive technical requirements lead to expensive tailor-made realisations, which in turn prevent generic solutions, and thus the advantages of mass production cannot be utilised. The implementation of modular design, both in software and in hardware, is needed if we want to get good results at reasonable costs. Also, we need to be able to standardise the interfaces between different modules and towards environment. The final goal is that different plug-and-play subsystems and modules, such as navigation or machine vision modules, will become commercially available for everybody. In that case, resources could be focused on developing real applications and the actual product development would become cheaper, easier and faster. The concept of modularity might just be the decisive step for a breakthrough in mobile robotics; currently, there simply are not enough resources available for every research group to develop everything by themselves.

1.1 Definition of module

A module is an elementary functional unit that can easily be exploited in a different kind of application. A module for mobile robots is defined in Virk 2003a as follows: "A module for mobile robots is described as any functionally complete device, or sub-assembly, that can be independently operated and can be readily fitted and connected to, or in combination with, additional modules to comprise a complete and functionally reliable system." For example, a plain sensor component is not a module because the use of it requires signal processing and programming. If a digital databus is implemented to the sensor, this brings it closer to the definition. When the sensor is a fully plug-and-play component (e.g. USB-bus adaptive), it fulfils the module definition perfectly. A module is typically an independent versatile unit that can be connected to different kinds of devices. Also, for example, an analog sensor with remote software fulfils the definition of a module. The remote software should include not only the drivers but also some upper-level components that can, for example, process and analyse the data.

The Oxford English Dictionary (http://dictionary.oed.com/) defines the term module as "a component of a larger or more complex system. Any of a series of independent units or parts of a more complex structure, produced to a standard design in order to facilitate assembly and allow mass production. More generally: any more-or-less self-contained unit, which goes to make up a complete set, a finished article, etc."

Modules consist of mechanics, electronics and software or some combination of these. Generally, modules that include mechanics also have at least electronics and, very often, software as well. For example, robot joints could be considered to be this kind of module. Sensor modules typically include electronics and software. User interface software, path-planning software and speech recognition software are examples of software modules. These modules are typically operated in close coordination with modules that include electronics and mechanics, but the modules might also act as clearly separated modules interacting only with other software modules. Each module has its own tasks, but several modules might have the same task. Most modules should have such roles that damage to one module would not paralyse the whole machine, but merely limits its capabilities to some degree.

Modules are connected to each other and to the rest of the system using interfaces. Figure 1 shows a set of interfaces that must be taken into account when attaching new modules to the system. The model has been developed in the CLAWAR[1] network. These interfaces include power (electrical, pneumatic, hydraulic), databus (communication databus, e.g. CAN, RS232, IEEE 488), mechanics (mechanical connectors, physical connections, joints types, range of movements), analogue (analogue signals), digital (digital signals, 0 or 1) and environment (surrounding environment and medium; air, water, dust, pollution, radioactive).

Figure 1 gives an example of how different modules can be connected to the various interfaces. The research work carried out to promote the modularity aims to standardise these interfaces. If this were to be achieved, the module developers would know exactly what kind of interfaces the modules should have. Standard interfaces would thus make the development of new modules much easier. The significance of modularity and standardisation as a driving force for the future expansion of a service robot market was emphasized by Bill Gates in Scientific American article (Gates, 2007).

Modules in the case study, presented in more detail in Chapter 4, are classified on the basis of the modified CLAWAR representation. There exist also decentralised modules, such as analog sensors, whose sensor and software are located separately. Super modules include several basic modules (Figure 2). Super modules correspond to superstates in UML (Unified Modelling Language). See, for example, Larman 2002.

Modules communicate with each other. They can also perform independent continuous functions (e.g. environment perception), in which case they can produce information continuously for the other modules and the system. Some modules produce services on request; these include actuator modules, for example.

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[1] The CLAWAR network was active in 1998-2005. It has been funded by the European Union as one of the first industry-led "thematic networks" investigating state-of-the-art technologies in Europe. The purpose of CLAWAR is to investigate and report upon all aspects of technology and systems relating to mobile robotics. (http://www.clawar.com)

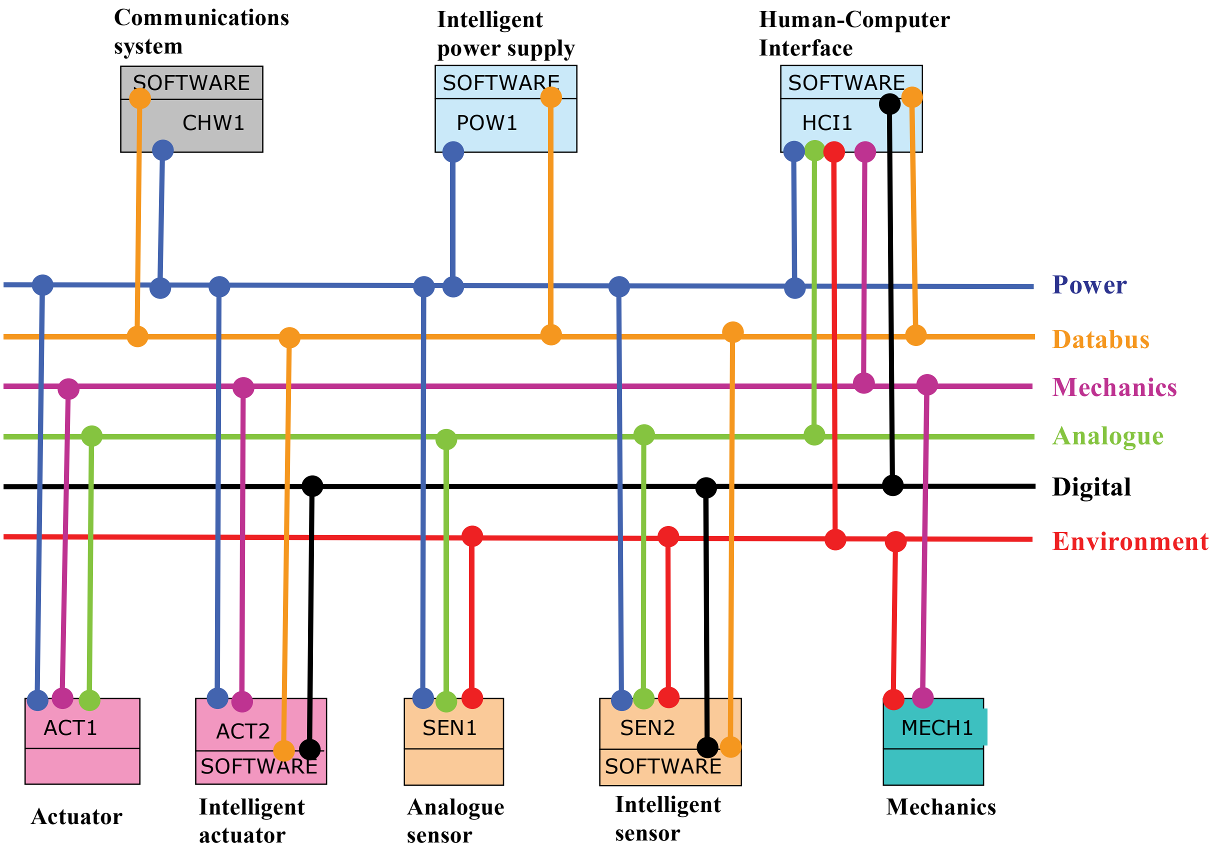

Fig. 1. Interfaces of modules (Virk, 2003b). The model has been developed in the CLAWAR network of the European Union.

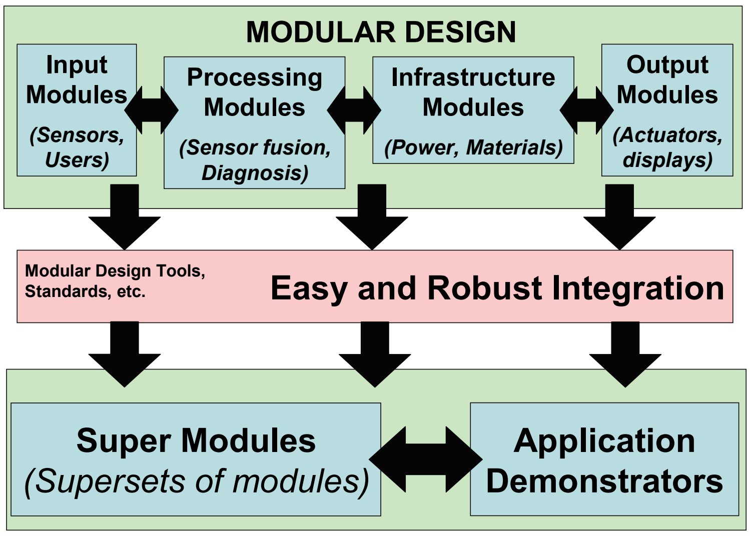

Fig. 2. CLAWAR design of modular mechatronic systems

Figure 3 presents system architecture typical of a modular service robot. Its idea is to demonstrate modules that are normally included in a service robot. Power (Pwr), Databus (Data), Mechanics (Mec), Analogue (Ana), Digital (Digi), Environment (Env) represent connections that might be needed for the modules. A CPU-unit is the central computer of the robot and all the modules inside it are software modules. The CPU-unit is not a module, because it is a common platform that can offer services for several software or hardware modules. The presented modularity structure is based on the WorkPartner, but similar structures can be found from most of the current service robots. Minor differences can be found in how the modules are implemented the practice and in the nature of their interfaces.

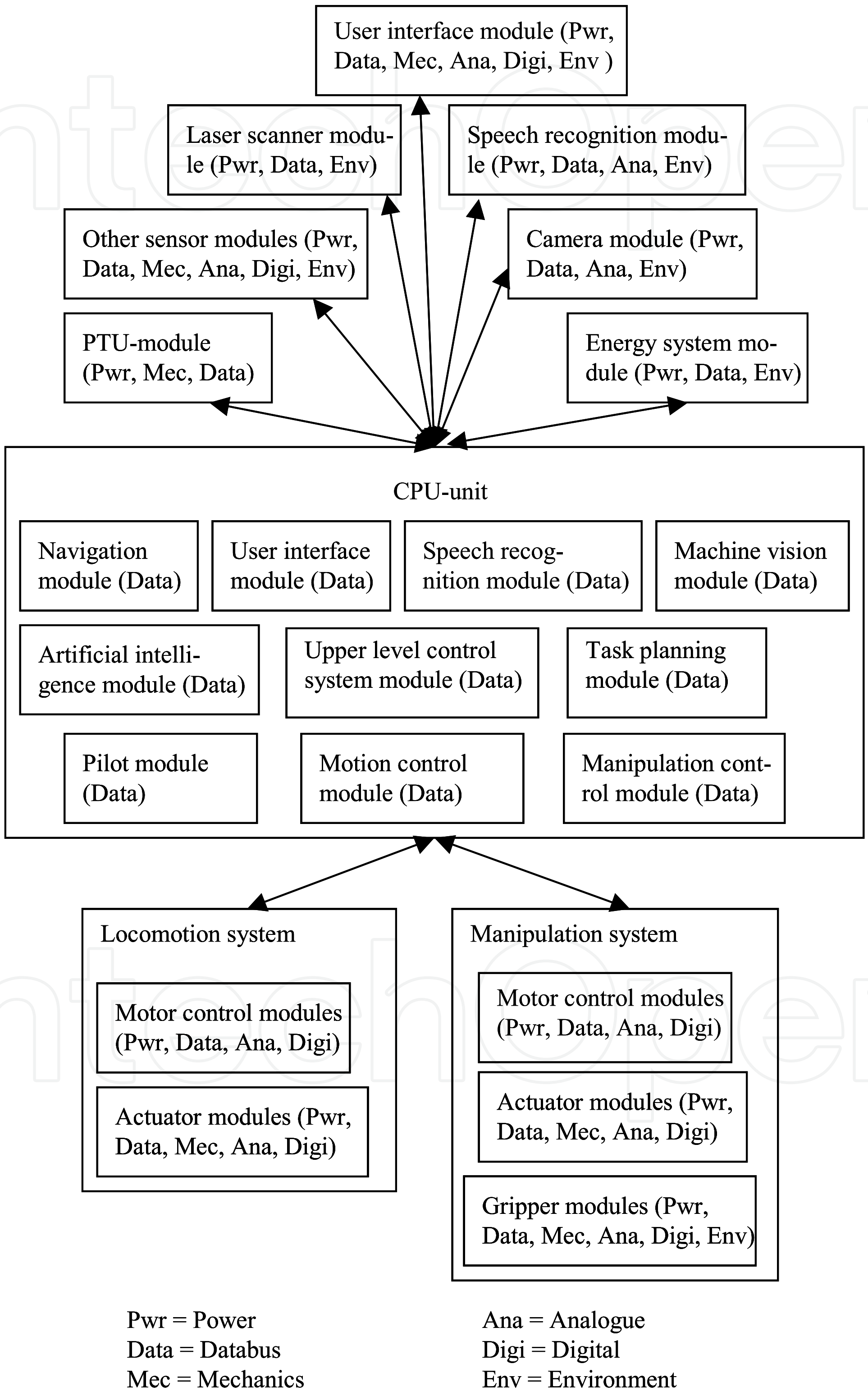

Fig. 3. System architecture of a modular generic service robot

There is a huge variety of different kinds of camera modules, data buses and mechanical connections available for the robot designer. From the standardisation work point of view, it is not so relevant that there are so many type of modules. It is far more important to focus on the standardisation of the connections, so that these modules can easily be connected to the robots.

2. Motivation for modularity

A significant amount of money has recently been invested in the research and development of service robotics around the world. Individual research groups, due to the lack of commercial off-the-shelf modules, have developed most of the applied subsystems separately. In an optimal situation, various plug-and-play modules would be commercially available. Utilisation of these kinds of modules would boost the service robot development and big savings could be gained. This would push the commercial supply and make cheaper prices possible, and again increase the demand. Thus, the coupling between demand and supply would operate in a healthy way and the service robotics industry could meet with real success. As in most branches of the engineering industry nowadays, in order to have a real success, the manufacturer has to pay a lot of attention not only to the design and manufacturing phases, but also to the commercialisation of optional accessories and maintenance services during the lifetime of the robots. The concept of modularity supports these operations perfectly. Additional features can be purchased and implemented easily due to the modular design, and the maintenance procedures are more straightforward when modularity has been applied to the product.

2.1 Needs in the area

The generalisation of consumer applications in service robotics still needs a lot of work. The biggest challenges are the complexity of the technology and finding proper applications. The complexity of technology increases the challenges in development, for example, as well as the development costs and the price of the end product. If the product is very complex and production amounts are low, the price will be very high. Standardisation of robot modules and their interfaces would help significantly. With standardised modules, a situation where there were different developers for robot modules and for robot applications could be achieved. The module market would have a larger volume, because the same modules could be used in different applications. Robot developers could focus on developing real applications, as they would not be forced to use so many resources for developing low-level techniques.

Developing and manufacturing non-modular service robots is technically very complex and challenging, so it costs a lot. Designing a modular service robot is much more straightforward.

2.2 Impacts of the modularity

Development speed of service robotics

High-level modularity would greatly boost the development speed of service robotics. Nowadays, service robot developers have to develop almost all subsystems and modules by themselves. If several modules with standardised interfaces were commercially available, it would help very much. Service robot developers could buy commercial modules from the market, implement modules to the system and devote their main effort to the development of real applications. Much time and money would be saved.

Fault tolerance

Modularity greatly increases the fault tolerance of systems. The the system dependence of single modules should be minimised. So, if a single module were to be damaged, the system should notice it, while the other parts of the system still can do their own work tasks. In that case, the system could re-route the communications. The most critical modules should be doubled.

Commercialisation of service robots

Modularity would make the commercialisation of service robots much easier and would help to develop much better robots than would be possible without it; it would also assist in making cheaper service robots because of savings in development and manufacturing costs. Manufacturing costs would be lower due to reasonable module prices. Modularity would also make manufacturing faster and cheaper because there would be many fewer different parts in the assembly phase.

Commercialisation and markets of modules

The same commercial modules could be used in several different applications and they would also boost the marketing of service robots, so appropriate modules would reach real mass markets. This would also assist in obtaining low prices for modules.

2.3 Advantages and disadvantages of modularity

Modular structures and modularity would in any case provide many advantages to service robotics, such as, for example, all impacts mentioned in the previous chapter. Smaller design costs and bigger volumes per module leading to cost reduction and the possibility of making more complex devices are also remarkable advantages. Reliability of modules and thereby also reliability of service robots could improve, because more time and effort could be used in the development work. Modularity and standard interfaces would also make modification of the robots easier.

The only clear disadvantage of modularity is limitations in the design. This comes from a limited selection of modules. The robot has to be built using the modules that are available. It could have an effect on connections, control software, size, outlook and features of the robot.

3. State of the art in modularity of service robots

3.1 The history of modularity

Modularity has a long history. During World War II, Otto Merker investigated how modularity could be implemented in the construction of German U-Boats. It was the first prominent case where modularity was implemented in technology. (Arnheiter & Larren 2006)

Modular production – this term was used for the first time in 1965 by Martin Starr in the seminar article “Modular production – a new concept”. He compared traditional mass production to modular production. (Arnheiter & Larren 2006)

In 1980, IBM launched modular architecture for personal computers. Nowadays, modularity is very strongly present in many sectors of industry. Modularity has been present in service robot development in some form from the very beginning, but no standardised service robot interfaces have been developed yet.

3.2 Interfaces of modules

Today there do not seem to be standard interfaces developed for service robotics. Standard interfaces are one of the most important things for promoting modularity in service robotics. Big technology companies like Sony and iRobot have their own interfaces between robot modules, but detailed information about these modules is company confidential.

In the research projects, it is reasonable to use standard interfaces, which exist in the other sectors. Several useful interfaces can be found in information technology. For example, USB, Ethernet, CAN-bus and RS-232 hardware data connections are used in many robots. Software interfaces for previous hardware interfaces are often manufacturer orientated and there are not any dominant standards.

3.3 Current standards

Several standards exist in industrial robotics currently. Most of them are safety standards for both stationary and mobile industrial robots. Driverless trucks are almost the only mobile industrial robots in use currently. For mobile service robots there are not any standards, while it is a very urgent need to establish at least safety requirements for them. Under ISO/TC184/SC2, an Advisory Group worked on standards for mobile service robots. The main goal of the group was to promote safety standards for mobile service robots.

3.4 Imaginary modular service robot

Designing modular service robots can be divided into individual phases. Figure 4 describes the starting point in service robot design. Robot, task and environment have tight interactions between each other. For example, if the task and environment are known, the robot should fill their requirements. The later phases from the modularity view are:

1. Listing of needed functions
2. Technology segmentation into subsystems
3. Segmentation into modules
4. Identification and searching of modules.

The list of needed functions includes all tasks that the robot should be able to do. The functions define the subsystems that are required for the realisation of tasks. Next, the subsystems can be divided into different modules. After this, a search should be made to ascertain whether commercial modules are available or whether tailor-made modules should be used.

Figure 4 presents a wide range of different kinds of commercial modules that could be used the service robots. It shows that the starting point is quite complex and that there are several different kinds of modules available. With these commercial modules, it could be possible to realise a service robot that could do simple locomotion and manipulation tasks. First, the wheeled mobile platform can be found from the modules. Stereovision, laser scanner, compass, gyro, arm and gripper modules can be mounted onto it. Hardware needs also a power module that offers the needed voltages for the listed modules.

Software is a much more challenging task to be solved using commercial modules. Mobile Vision Technologies GmbH sells the ERSP3.1 software module, which has been developed for the control of vision, navigation and user interface modules. However, central software, which controls the operation of the whole robot, has to be programmed. Central software controls all the other modules and is responsible for decision-making inside the robot.

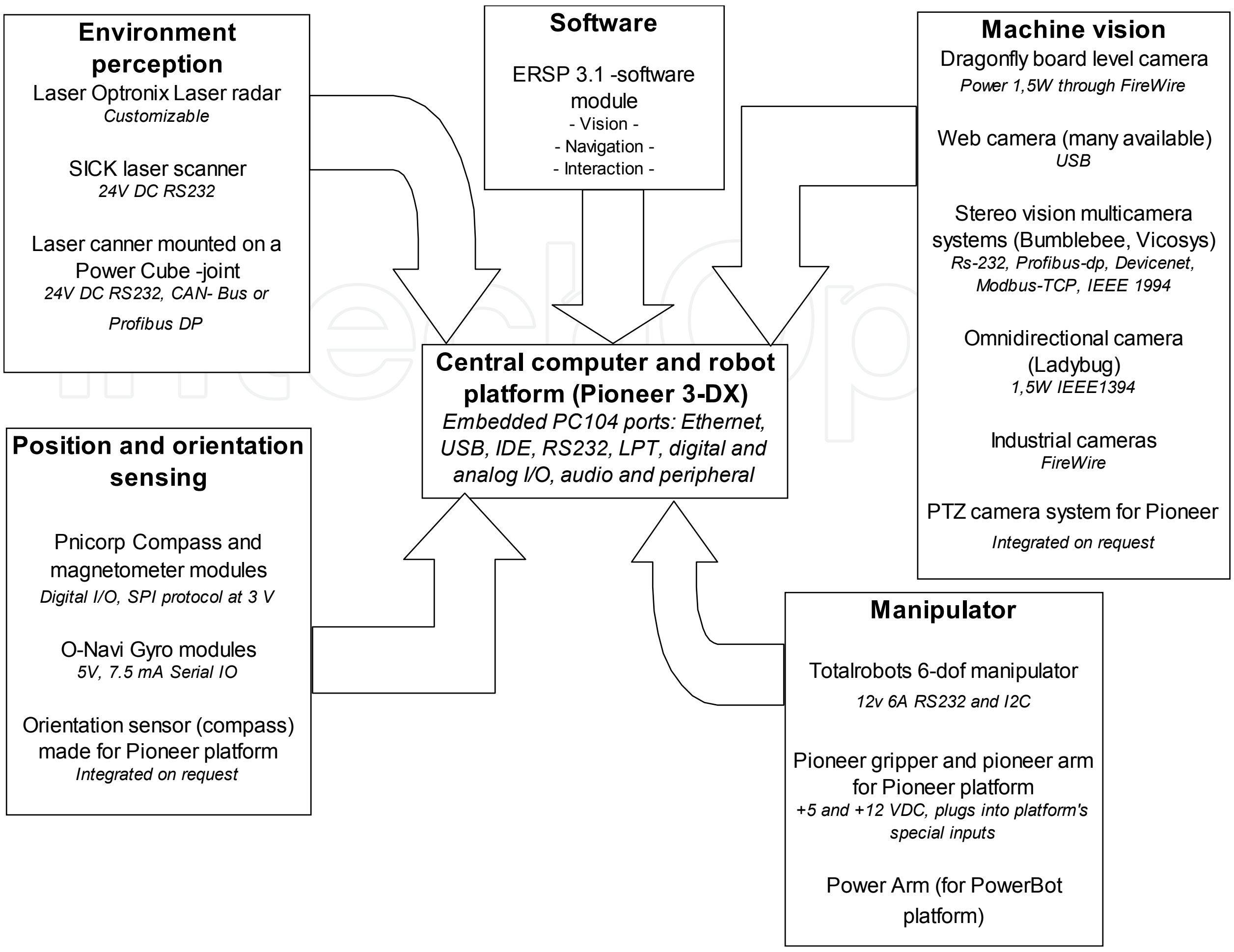

Fig. 4. Structure and interfaces of the imaginary modular service robot. The figure presents a group of potential modules and their interfaces.

As a conclusion, it can be noted that already several different modules are commercially available, but it is not possible to build a working robot out of these. There are big differences between the mechanical interfaces of modules too. So even mechanical assembling needs good workshop and a professional mechanic. Central software programming and work-task generation needs a large amount of work, even from the field's expert. The designer of the robot should program an advanced user interface too. Modular work-task generation, which is introduced in (Terho et al., 2006), would help a lot if it could be made available as a standardised product.

4. Case study: WorkPartner

This following analysis presents an example of modularity using WorkPartner service robot as an example (see Figure 5). WorkPartner is a multifunctional service robot for outdoor tasks. Some possible work tasks are garden work, guarding, cleaning, transporting lightweight objects and environment exploration including mapping. Mobility is based on a hybrid system, which combine the benefits of both legged and wheeled locomotion to provide at the same time good terrain negotiating capability and large velocity range. The working mechanism is a two-hand human-like manipulator, which can be used for a variety of tool manipulation tasks.

The robot is divided into functional subsystems that are relatively independent as to their software and hardware. The main subsystems are: Locomotion subsystem, Manipulator, Energy subsystem, Navigation and perception subsystem, Upper level task control and monitoring system and Human-machine interface.

Fig. 5. WorkPartner picking up litter

Next, two of the subsystems of WorkPartner are described in a more detail. The purpose of the analysis is to demonstrate the ideas of modular design through a case example. More information of the modular design of WorkPartner can be found in (Ylönen, 2006).

Manipulator sub-system

The platform is equipped with a two-hand manipulator system. The manipulator is made of aluminium and weighs only about 30 kg. The manipulator can handle loads of up to 10 kg. A two-hand human-like and human-size manipulator was chosen because similarity to human tasks and close co-operation with people are required.

The manipulator consists of a 2-DOF (degrees-of-freedom) body, two 3-DOF arms and a 2-DOF camera and distance measuring laser pointer head. The manipulator's body is joined to the platform with two joints that allow orientation in horizontal and vertical directions. Fig. 6 describes modules of the manipulator and their connections. Mechanics modules are connected with joints to each other, except the head, which is connected to the pan-and-tilt-unit. As an exception of the mechanics modules, wrist modules have an additional connection to the environment, because they can be used in handling objects. In the manipulator there are 10 supermodules, which are equipped with DC-motors, harmonic type gearings, mechanical breaks (wrists and gripper excluded), potentiometers and motor drives. Each motor drive controls one or more joints. The supply voltages for the joint motors are 48 V, 12 V for the brakes and ±12 V for the gripper. Motor drives are based on Texas Instrument DSP processors. Drives are equipped with a CAN interface, analogy inputs and digital inputs and outputs. Message structure on the CAN-bus includes message type and the data itself.

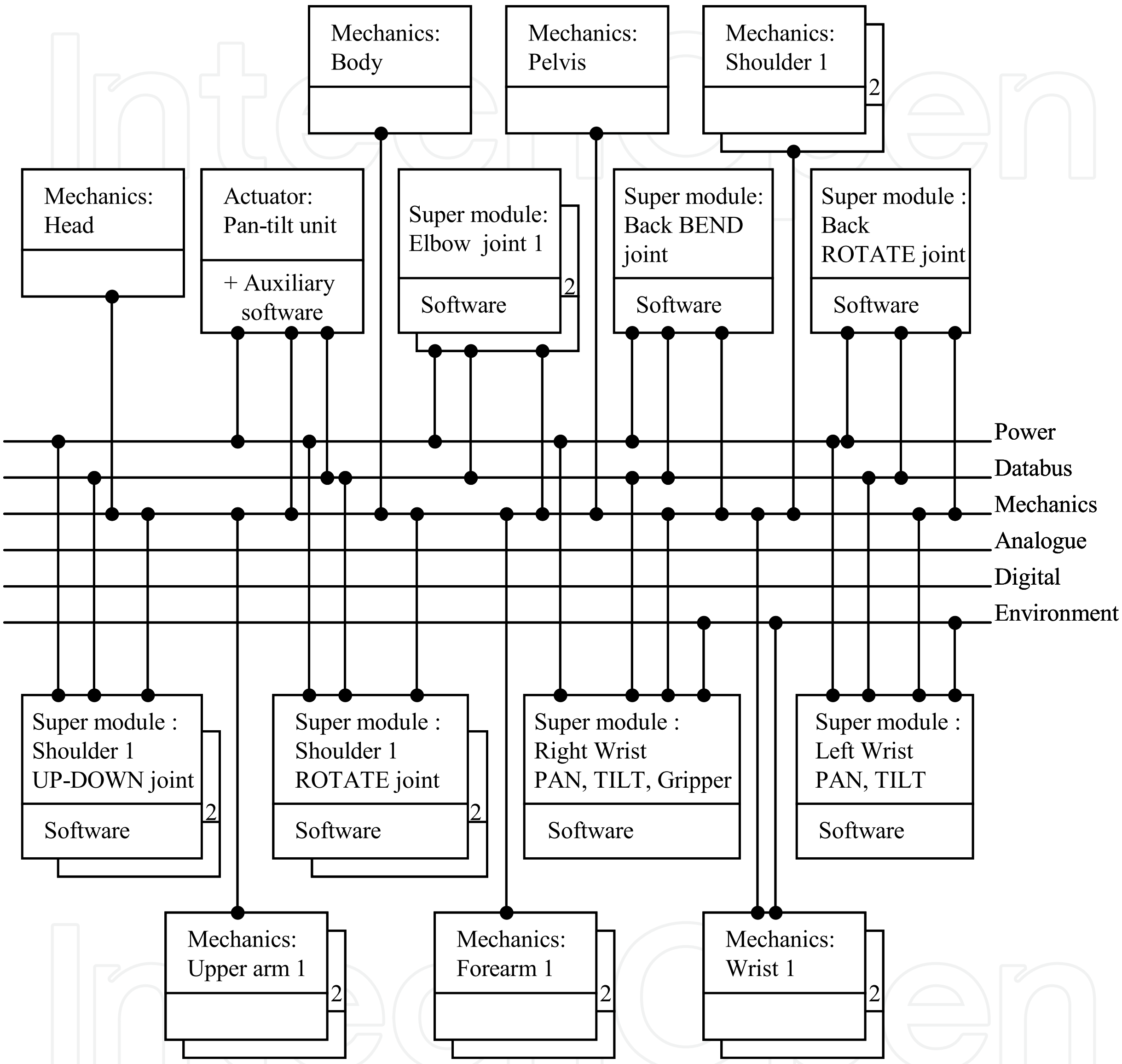

Fig. 6. Modules of WorkPartner's manipulator according to modified CLAWAR model

Human Machine Interface

The Human-Machine-Interface (HMI) of WorkPartner is designed for operators working in parallel to the robot and, in some cases, co-operating very closely with it. However, the remote control mode is also possible when the robot is accessible via the Internet. Symbolic representation in communication is based on the underlying idea that both the operator and the robot perceive the same environment and interpret it through a commonly understood virtual model. The model is a simplified 3D description of the environment, which includes the objects relevant for performing work tasks. Modules of the HMI are presented in Fig. 7.

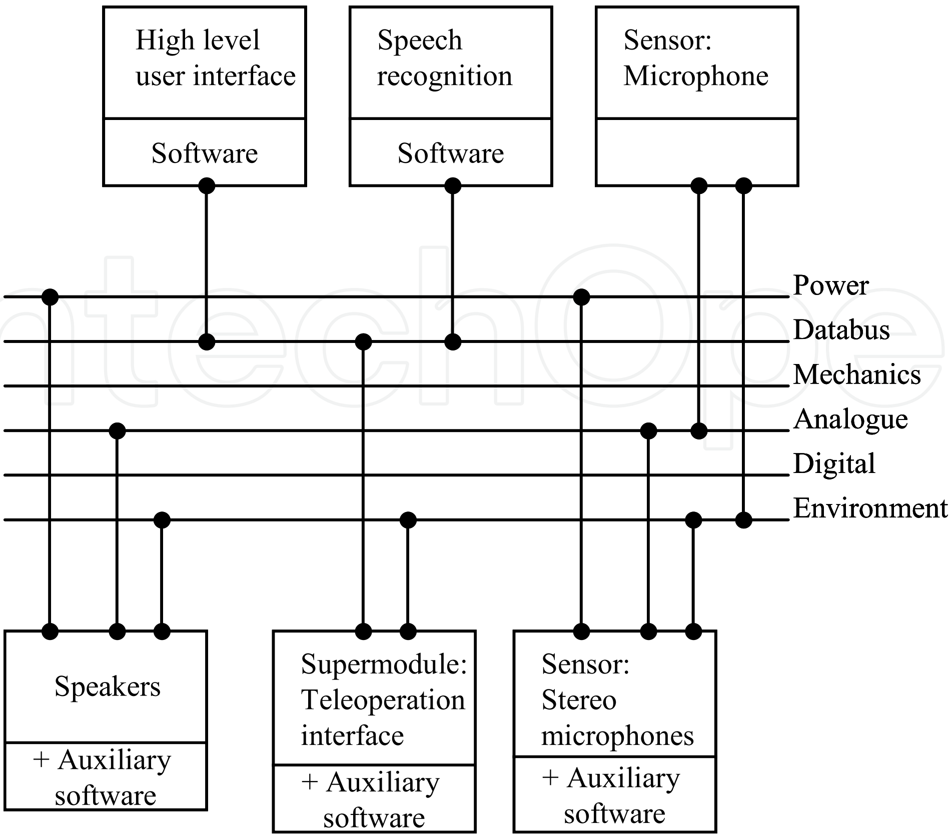

Fig. 7. Modules of WorkPartner's human-machine interface, according to the modified CLAWAR model

Speech synthetisation software generates a signal for the speakers. Speech recognition software, currently Microsoft Speech, interprets microphone signal as words.

Stereo microphones are located at the shoulders of the manipulator. They are used for detecting the direction of sound. When having a "conversation" with the human operator the robot turns its head towards the direction of the sound. A key part of the HMI is the wearable teleoperation device, which is classified as a super module. The teleoperation interface is presented in Fig. 8.

It can be used for teleoperation, teaching of movements and for giving commands by gestures. It is connected to the user interface laptop through an RS-232 serial bus. Software calculates arm orientations and generates different kinds of control commands.

5. Actions for improving modularity

For some time, there has been a strong demand for common mobile robot standardisation. Current robotics standards have been focused on the stationary industrial robots. Safety issues in the industrial robotics have been based on the fact that people cannot go to the working area of robots. Therefore, these standards cannot be utilised for mobile robots, whose essential idea is to act and work in the same environment as people.

Some safety standards developed for automatic forklifts could be adapted to service robotics also. These standards define, for example, that maximum locomotive speed is 1 m/s. For stopping the vehicle, it has been stipulated that a person must not in any case be run over. Standards stipulate also that, even if a person lies on the driving way, the automatic truck has to observe him/her and stop early enough (SFS-EN 1525).

Fig. 8. Teleoperation of the robot with the wearable teleoperation interface.

ISO established the Advisory Group on Standards for mobile service robots. The group worked under ISO/TC184/SC2. The work is introduced in (Virk 2006). The size of the group was about 30 experts from around world and there were also delegates from IFR (International Federation of Robotics), IEEE Robotics and Automation Society (IEEE is Institute of Electrical and Electronics Engineers) and IEC/TC 44 (International Electrotechnical Commission / Technical Committee 44). The goal was to start the project that defines safety standards so that these standards can be taken into use. The first goals of service robotics standardisation are to define terms relating to how service robots should act. A big problem at the moment is that there is not this kind of standards, so it is not possible to commercialise service robots that fill such standards. From this it follows that a commercial mobile service robot would not be legal. After safety standards for mobile service robots are ready, robot manufacturers can put service robots that meet these standards, and are thus legal, onto the market.

Standardisation work has to be continued with respect to module interfaces too. Standards, which have been developed in the other sectors, should be used as much as possible in software interfaces. For example, software standards in Internet-related applications, the car industry and work machines. Complementary standards can be developed in addition.

Modularity should also be improved in co-operation networks, which could be sponsored by EU or which could work under a currently existing robotics association. Information about modularisation benefits should be shared so that as many as possible become highly motivated towards modularity development. This topic should be taken note of in education too. Different kind of competitions is good way to teach new things. Public example cases could show in reality the benefits that can be derived from modularity.

6. Conclusion

Service robotics has been an active research and development area for more than ten years. However, most of the subsystems needed to create a fully operational service robot have been developed separately by individual research groups. Modularity could be the key factor to success by reducing the development time and by increasing the technical advancement level. Thus, it could directly help to gain significant savings on the total development costs. The reliability of the subsystems would also be improved, because more time and money could be used for that. Modularity, and especially the work with standard interfaces, would also make the modification of these robots much easier.

The case study in which the concept of modularity has been studied is that of the WorkPartner robot. This is an advanced service robot, in which most of the important modules in service robotics have been integrated together successfully. The utilisation of modularity in this project was essential due to the high hardware and software complexity of the robot required to complete the given working tasks. This case example also demonstrates very clearly that significant savings in the development time and costs could be gained if commercial modules for service robots were available.

Standardisation work is needed for boosting modularity. If the interfaces of the modules could be standardised, this would create a far better operational environment for the current and future module producers. Safety standards are required before more generic service robots can be released to the wider market. Currently, there are safety standards for industrial robots and automatic forklift trucks, but these standards would require at least a considerable amount of modification before they could be more widely applied to the field of service robotics.

Modularity is clearly essential for the successful development of reasonably priced service robots. Right prices will boost the demand for service robotics and that, in turn, will direct more effort to service robotics development in general, and thus a positive cycle would evolve. One could safely state that modularity will be one of the key factors that is required to guarantee that the service robotics industry will reach global success in the near future.

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This book consists of 18 chapters about current research results of service robots. Topics covered include various kinds of service robots, development environments, architectures of service robots, Human-Robot Interaction, networks of service robots and basic researches such as SLAM, sensor network, etc. This book has some examples of the research activities on Service Robotics going on around the globe, but many chapters in this book concern advanced research on this area and cover interesting topics. Therefore I hope that all who read this book will find lots of helpful information and be interested in Service Robotics. I am really appreciative of all authors who have invested a great deal of time to write such interesting and high quality chapters.

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