

Development of Mobile Robots - A Proposal of an Open and Flexible Control Architecture

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Abstract. This work presents a model of an open control architecture for the development of applications with mobile robots. The software explores the computational power of mobile devices (i.e. PDA) for the embedded system and the system of wireless communication for access to a remote computer and the Internet. The software architecture, with hierarchic characteristics, distributed in increasing levels of complexity with resources of reconfigurable computation and embedded systems exploring the technology of mobile devices, directed to the cooperative development of applications of the Mobile Robotics. The hardware is based on a net of sensors and actuators. Each sensor and each actuator are controlled individually by microcontrollers. The modules of the developed hardware and software are structuralized in independent parts, considering architecture of open implementation and allowing the easy expansion of the system (software and hardware), better adapting the platform to the diverse tasks associated to it.

Keywords: Embedded Systems, Control Architecture, Reconfigurable Systems, PDA devices, Wireless networks.

1 Introduction

The development of control architectures of mobile robots faces some difficulties as of hardware as of software. Each application can demand particular situations of development either for the mechanical aspect, for the electronic or the computational one. Thus, an interesting model of development is well characterized for the easiness of adaptation to a new situation and allowing the reutilization of parts or the whole of other initiatives. This means that the demanded flexibility requires a model primitively well established of hardware and software that offers an environment of open development, flexible and scaleable. Possibly, this model can be obtained based in an operational net of sensors and actuators and by a management protocol of resources not centered and with computational embedded power that allows the

implementation of embedded control loops supported by the one of the state of the art technology.

The existing computational capacity in the PDA current allows its use in different domain of application, for example the use of PDA as embedded computer for use in mobile robots, which used as computational device with communication easiness, allows the reduction of the complexity in the construction of mobile robotic systems.

The use of PDA, with wireless communication, allied with the architecture concept client/server (C/S) facilitates the construction and extends the universe of use of mobile robotic systems, eliminating the designer of the necessity of conception of the whole system of communication between the mobile robot and the central station of control, inasmuch as most of the functionalities is implemented in the operational system and in the hardware integrated to the PDA.

At the same time can assist the designer offering an open platform for software development, this means, most of the time the operational system of the PDA offers a set of functions for development of applications known as API (Application Programming Interface). It extends due to the offering of a solid and flexible base for the project of robots, making possible to concentrate only in the construction of the application of the robot in specific domains.

Proposals and projects of robotic systems based in architecture C/S are not new features, [1], [2] and [3] are argued in this work, and systems of controls of long-distance robots using Internet technology can be found in diverse works such as [4] and [5].

On the other hand, as cited, the flexibility offered by the software architecture must be followed by the hardware architecture. This way, the hardware architecture is based on a net of sensors and actuators. Each point of access, a sensor or an actuator, is carried through by a microcomputer, forming for this set, a module. Modules can be inserted or removed from the net according to the necessity of each application. Moreover, the standard of connection established, followed by preset characteristics of software, becomes the net formed for the modules open and reusable. Each microcomputer presents characteristics according to requirements of the sensor or actuator by it controlled. The microcontrollers communicate through the physical layer available by its manufacturer. A central module of control does not exist, but a module of entrance and exit of the net that communicates with the PDA to gain wireless access to external computer network. Moreover, the PDA is hold as the element of opened and flexible processing, of high level, for the system of embedded control.

The objective of this work is to present a proposal for construction of robotic systems mobile autonomous worker on the basis of the concepts of architecture of software based on the concept Client and Server, in a net for slide bars of sensors and actuators, open and flexible, and nets of wireless communication that support the some architectural approach and applications.

2 Architecture of Control

The project of mobile robots requires the evaluation of a considerable set of variables. Questions such as degree of autonomy, mobility and navigation through the environment directly influence the conception and construction of the robot. The growth of the functionalities of a robot is directly proportional to the complexity of the same. However, nor always it is possible to accommodate in a mobile robot all the desired functionalities. To balance desires and restrictions in a project of mobile robots is, most of the time, a complex task.

Unlike a software project, a mobile robot project requires the integration of elements of software electronic and mechanic engineering. Many times is necessary to choose or even to build all constituent elements of a mobile robot, which is, since the hardware until the software components, as operational system or monitorial program, of the robot and the application properly said.

The development of a mobile robot certainly is guided by the application. The environment determines the physical characteristics and the form of robot's navigation.

However, besides the navigation, other questions must be managed to keep the integrity and the survival of the robot. To guarantee the navigation of the robot for the environment allows the accomplishment of the task demanded for the application.

To minimize the increasing complexity of construction of mobile robotic systems, it can opt to the job of partition strategies and abstraction. The partition consists on the division of a bigger problem in smaller parts (divide and conquest) and the abstraction, in determining different levels of services among a function.

The use of architecture client/server (C/S) is a form of partition and abstraction. With this architecture it is possible to divide and to distribute the functions of a mobile robotic system between two separate entities. The client side is implemented in the mobile robot and the server side in a fixed computational system, that is, in a computer. The communication between the parts client and server is carried through a computer network. The main objective of the choice of an architecture C/S is to gain flexibility in the project of mobile robots.

A flexibility example is in the implementation of the process of decision of action of the robot. One part of the process of decision can be implemented in the proper mobile robot and another one in the server, as it shows Fig. 1. Questions related to the survival of the robot must be processed quickly and locally. More complex decisions can be passed to an up level coordinator.

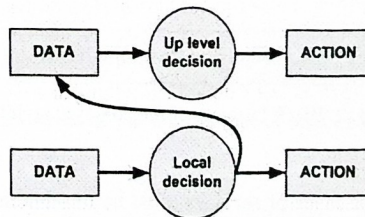


Fig. 1. Levels of decision.

The proposal contemplates the abstraction by means of the use of a structure of layers of services as in the side client as in the server side. The main objective is to facilitate the development of applications by means of the fast prototype with reuse of components, as much of software as of hardware. Each layer offers a set of specific services for the immediately superior layer. Inside of this model of construction of mobile robotic system, whoever develops the application of use of the robot does not need to construct everything from the zero, is only enough to know the functionalities offered for the inferior layers. Moreover, the considered model can be extended, that is, new functions in any layer, can be created and offered.

The proposed structure is composed of three layers: layer of application, layer of services and layer of the robot, as shown in Fig.2. In the first layer, inferior level, is the layer of the hardware of the robot. This layer supplies the structural base (mechanics) of the mobile robot, presenting the mechanical characteristics and the system of sensors, as well as the firmware that implements the local control of the robot. The intermediate layer is the layer of services. This layer is divided in two sub layers: sub layer of the client and sub layer of the server. In the sub layer of the client are implemented the functionalities that allow the construction of the application that controls the robot directly, as well as the functions that allow the communication between the sub layer of the client and the sub layer of the server. One of the objectives of the sub layer of the client is to allow the implementation of reactive architectures, behavioral or hybrid in local level, that is, next to the robot. The incorporation of processing power in the robot or next to the robot is a form of supporting this. The sub layer of the server has as objective to extend the functionalities of a mobile robot, allowing an additional level of implementation of architectures with more deliberative profile. With the sub layer of the server it is possible to generate a superior level of taking decision of the robot, besides allowing the construction of a central repository of information captured by the robot.

Application layer	software development tools	
	Software components (building blocks)	
Service layer	Server side	Server applications
		API for server applications
	Client side	Client applications
		API for client applications
Robot base layer	Firmware layer	
	Sensors / Actuators	
Mechanics and computer hardware		

Fig. 2. Block Diagram of the proposed architecture.

All the functions of the layer of services must be implemented and packed in an API or even, in two distinct APIs: one of the sub layer of the client and another one of the sub layer of the server. In the superior layer, it is the application layer. In the

application layer there are the tools of development and the components of software for construction of the applications or for the layer of services, as much of the server side as the client side. The components of software of the application layer are abstractions in the class form and object of the API of the layers of the client and the server. The application layer must favor the construction of tools of development that use the software components and facilitate the development of applications.

In the proposed architecture, the interface between the layers is implemented through software components (objects and classes) that carry through calls to an API specifically constructed to offer support to each layer. Each API in each layer implements primitive functions of operation of the layer, as well as services of communication with the adjacent layers.

The sub layer of the client is embedded physically in the robot and its implementation consists of the use of architecture of flexible control, in the case of this work, of a device PDA. The decision for the use of a PDA is based on the fact that it is a ready hardware that uses standardized interfaces, as serial interface and wireless communication, and an incorporated operational system. This set of characteristics favors and reduces the effort for the development of the components of software and the API necessary for implementation of the sub layer in question.

It is relevant to detach that the PDA could be substituted by specific hardware, for example, a plate of reduced size of a same PC architecture or for a customized device based in microcontroller. However, such solutions would demand greater efforts to configure the environment, since the hardware until the installation of an embedded operational system. In the case of the use of a micro controlled device, the necessary efforts for implementation of such easiness would still be bigger mainly considering the versatility searched in this proposal of architecture.

The layer of the robot or mobile robotic base is notoriously directed to the hardware and requires, also, cares due to its mechanic construction. The function of the robotic base is to allow to the mobility of the robot and the acquisition of information of the operation environment. In the proposal of this work, the base of the robot must be open enough to receive expansions, such as, inclusion of new types of sensors and/or actuators. For being highly dependent of the hardware, the layer of the robot requires special considerations related to its construction. A proposal would be to consider each sensor or actuator to be used in this layer, as a complete subsystem, which means, that it encapsulates all the functionalities and descriptions of functioning of the same. Instead of using a luminosity sensor, it would be necessary to construct a small system of capitation of luminosity. In the specification of this module the interfaces for configuration and use of the data collected for the system would be described. Easiness in the interconnection of these sensory modules or actuators in the architecture as a whole would be the main advantage in the use of this type of approach. The modules sensory /actuators could be integrated in a robotic base for an internal net of data based, for example, in standard I₂C or even USB. Fig. 3 shows the block diagram of the components of the internal net of data of the robot layer.

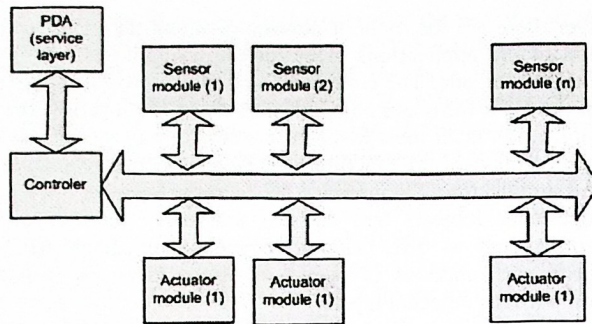


Fig. 3. Internal net of the robot layer.

3 Construction of the proposed architecture

The development of the proposed architecture requires the passage for different levels. The first one is associated with the construction of the proper architecture, which means, in the development of the API in the part of client as well as the part of the server; in the construction of a mobile base with a set of sensory modules and actuators; in the implementation of a protocol of control of the internal net of data of the robot; configuration of the elements of the wireless communication network that binds the robot to the server; in the offering of a minimum set of classes and objects for the construction of applications for the mobile robot and in the proper validation of the considered model.

The second level consists on the improvement and expansion of the considered model. Improvements through the addition of new functionalities and construction of environment of development of applications but directed to the final user.

The last stage is in the use of the architecture (Fig. 4) by the final user. In this point, the architecture must offer the necessary abstraction so that a user can create an application with what is available for it.

The mobile robot implements part of the layer of services, more specifically, the sub layer of the client, as well as all the layer of the robot, as presented in Fig. 5. The sub layer of the client is contained on the PDA, implemented in the form of a set of functions on the proper API of the operational system, for example, Windows CE or Palm OS. This way the API client carries through calls to the API of the operational system of the PDA. The communication between the sub layer of the client and the module of the robot is carried through by a direct connection between the PDA and the mobile base. The direct connection can be implemented through the use of serial communication standard, USB or IR (infrared) depending on the implementation of the control module of the internal net of data of the robot. The internal net of data of the robot, binds to the controlling element with the sensory modules and actuators (Fig. 4).

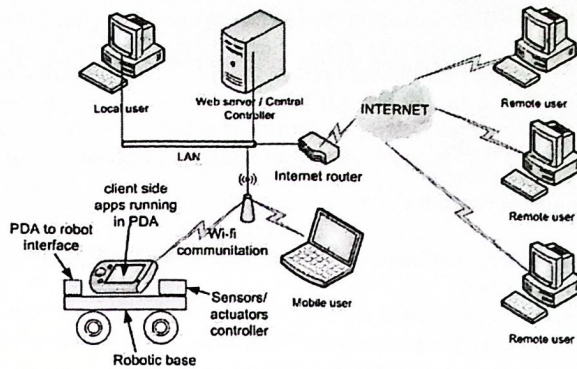


Fig. 4. System architecture.

All of the implementation of the module of control of the internal net of data of the robot is contained in firmware incorporated to the mobile base of the robot. In such a way, such firmware is responsible for the interface between the layer of the robot as the layer of services, in this case, the sub layer of client.

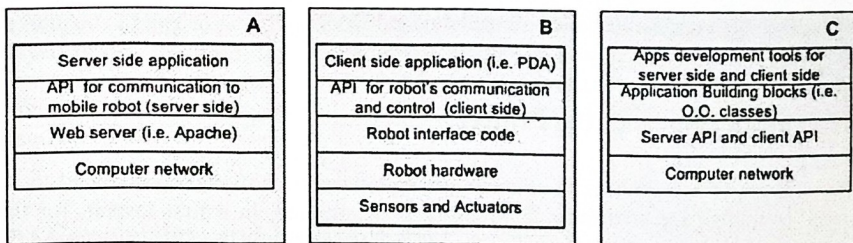


Fig. 5. Server, Client and Application.

The communication between the sub layer of the client and sub layer of the server is carried through by Internet technology, more specifically, through protocol TCP/IP. Functions of communication between sub layers of services are implemented as in the API of the sub layer of the client as in the API of the sub layer of the server. To facilitate the implementation of the side of the server, an HTTP server, for example, Apache, can be used to handle the communication. The application layer can be also divides between client and server. An application can be constructed to be executed only in the client, which means, loaded in the PDA for direct control of the mobile robot or can be divided between part in the client and part in the server. Functions of the API of the layers of the client and server offer support to this type of application. The functions of the API of the layer of services, are encapsulated in classes and

objects, called construction blocks of application, that provide a base construction of applications, Fig. 6, part C.

A- Side of the server: Definition of the primitive of communication between the server and the client.

- Send data to the client
- Receive data from the client
- Obtain status of the client
- Initiate communication with client

B - Side of the Client: Definition of the primitive of communication between the client and the robotic base.

- Main functions:
 - i) movement of the base: Right, Left, Front, Reverse Stopped;
 - ii) activation of devices
 - iii) reading of data and status of the sensors
- Definition of the primitive of communication between the client and the server.
 - i) To send data for the server
 - ii) It receives data from the server
 - iii) To obtain status of the server
 - iv) To initiate communication with server

C - Development of applications (Component Building Blocks)

- Robotic base
- Interface between the Robotic base and device PDA

4 Considerations of the Project

The success of a project of an autonomous mobile robot is directly associated to its mobility though the environment. Mobility is determined, in a first instant, for the mechanical characteristics inferred to the robot referred to the limitations imposed by the environment. In a second instant, the inserted sensors and actuators contribute to determine and to refine situations that better contribute for the mobility and survival of the robot in the environment. This entire situation is directed to the navigation of the robot in the environment.

The navigation difficulty is related with mobility and the quality attributed to the robot of feeling and reacting in the environment. Increased to this, weather the previous knowledge of the environment for the robot, falls again on as the architecture of control will treat the set of sensorial information and as to act to adapt itself in this environment. Certainly, the fact of the environment be dynamic propitiates some situations that determine the architecture of control, more reactive or more deliberative options, for the decisions taken during the navigation or the survival of the robot in the environment.

Historically, some architectural approaches register the search for the negotiation between the reactive extremity and the deliberative one in the control of the mobile

robots. Anyway, solutions found for a situation hardly are adapted to others. This evidences the difficulty of conception and development of architecture of control. Therefore, a development environment, with characteristics that facilitate the implementation and modifications in the control architecture and with modularity that allows the reuse of parts of architecture for the creation of a new one is extremely interesting. Moreover, the available resources follow an established and open standard that facilitates the exchange of information and the reuse among developed projects.

5 Proposal of Implementation

The described architecture is in development in the Laboratory of Systems Integration and Intelligent Devices - LISDI of UNESP campus of Bauru - Brazil. The versatility of the architecture can in such a way be explored in the development and validation of diverse architectures varying from the most reactive until most deliberative, [6], [7] and [8] as a group of benches of development for industrial mobile robotic applications in environment or specific applications as, for example, mobile robots for didactic use. Architecture open as proposed in this work, when adopted for a community, tends to grow, as much in the addition of functionalities as in the number of applications.

The model considered in open architecture offers different fronts of research. Research in the application layer can be directed to the construction of components of software and environments of software development. The layer of services can be extended, adding to new functions such as in the serving sub layer as in the client sub layer. In the first layer, layer of the robot, studies on new protocols of control of the internal net of data and also proposals for standardization for specification and construction of sensory modules and actuators, are subjects that deserve greater inquiry.

6 Conclusions and Future Works

This work presents a model of architecture for the project of mobile robots using PDA and devices of wireless net. The control structure is carried through using concepts of reconfigurable embedded electronics and considering the division of the system in diverse functional blocks, allowing a fast adaptation of the system to the new dedicated applications (service robots). This implementation was carried through by a multidisciplinary team, allowing to the consolidation of diverse works of undergraduation and graduation. This way, the implemented platform became a powerful environment for diverse activities of research, as for example, the validation of control strategies and supervision, generation of models of communication protocols, fusion and treatment of sensors, among others.

To facilitate the future modifications, implementations and tests, the use of reconfigurable embedded electronics in diverse blocks of the project is strongly emphasized. In fact, it was observed that systems of development based in reconfigurable logic present as characteristic a great capacity of adaptation to new

demands of the project. Another desired objective with this work is to get knowledge on this type of manipulator, aiming to provide alternative solutions for practical industrial problems, in the areas of maintenance, supervision, simulation and manufacture.

Some promising aspects of the resultant product are:

- It presents flexibility, because it has a great variety of possible configurations for solution of diverse types of practical problems.
- Is a powerful tool for validation of prototypes, allowing a simple solution for integration of sensors and actuators.
- Due to the use of reconfigurable logic, presents the possibility of modification of the strategies of control in real time.
- The implemented open architecture allows its use in academic activities.

The proposals of future activities are presented as:

- Optimization of the current prototype in terms of project and modularization.
- Validation of the architecture of control for other tasks, with new combination of sensors and actuators.
- Study and implementation of strategies of cooperation between different industrial mobile robots and services.

References

1. Brugali, D., Fayad, M.E.: Distributed Computing in Robotics and Automation. IEEE Transaction on Robotics and Automation. Vol. 18, n. 4, (2002) 409-420.
2. Kubitz, O., Berger, M.O., Stenzel, R.: Cliente-Server-Based Mobile Robot Control. IEEE/ASME Transactions on Mechatronics, vol 3, n. 2, (1998) 82-90.
3. Berger, M.O.; et al. A Modular Layered Client-Server Control Architecture for Autonomous Mobile Robots. In Proceedings of the IEEE International Symposium on Industrial Electronics. Vol. 2, (1997) 7-11.
4. Han, K.H.; et al. Implementation of Internet-Based Personal Robot with Internet Control Architecture. In: Proceedings of the 2001 IEEE International Conference on Robotics & Automation, Seoul, (2001) 21-26.
5. Ohchi, M.; et al. Development of Autonomously Mobile Robot with Control System Connected by TCP/IP Network. In: Proceedings of IECON'01: The 27th Annual Conference of the IEEE Industrial Electronics Society, (2001) 311 - 316.
6. Brooks, R.A. A Robust Layered Control System for a Mobile Robot. IEEE Journal of Robotics and Automation, Vol. RA-2, n. 1, (1986) 14-23.
7. Gat, E.: Integrating Planning and Reacting in a Heterogeneous Asynchronous Architecture for Controlling Real-World Mobile Robots. Proceedings of the AAAI92, (1992).
8. Elfes, A.: A Distributed Control Architecture for an Autonomous Mobile Robot. Artificial Intelligence, Vol.1, No 2, (1986) 135-144.