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Advanced Design Methods and Tools for Mobile Robot Development

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ABSTRACT

Development of mobile robots is a very difficult and time consuming task. If good development tools were available the development work would be more productive and products would be more reliable. In this paper we present an efficient design approach for mobile robot development and give an overall description of tools, which are useful during the development cycle.

INTRODUCTION

Common to most mobile robots is that their development has taken a lot of time and efforts. The productivity of the development work could be increased if design methods and tools were optimized to suit as good as possible to the development of mobile robots.

We have been studying problems involved in the mobile robot development phase. The goal is to develop a design approach that would minimize the needs of building prototypes to test mobile robot operation and maximize productivity of the work.

Because the development of a special tool takes a lot of time and is very expensive our approach is based on existing, preferably commercial tools, which are carefully selected to meet special requirements of multitechnology systems. Another criteria is that their should operate flexibly together.

We have concentrated on the development of a wheeled platform and especially to the development of moving capabilities of the platform. Due to this simplification suitability of this design approach to another type of the mobile robot development is not ensured.

Our test case is a wheeled manipulator platform. It will be able to move manipulator automatically from place to another in a simple structured environment, such as warehouse or office.

LOGICAL STRUCTURE

A mobile robot can be divided according to realization technology into three logical parts: software, hardware and mechanics (figure 1).

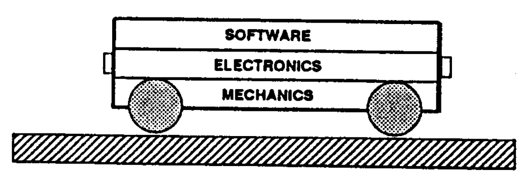

Figure 1: Basic structure

This categorization criteria is practical because each part has its special design problems and they usually are developed as separate entities.

More detailed division can be done according to several criteria. In figure 2 this division has been done from the point of view of design and simulation tools.

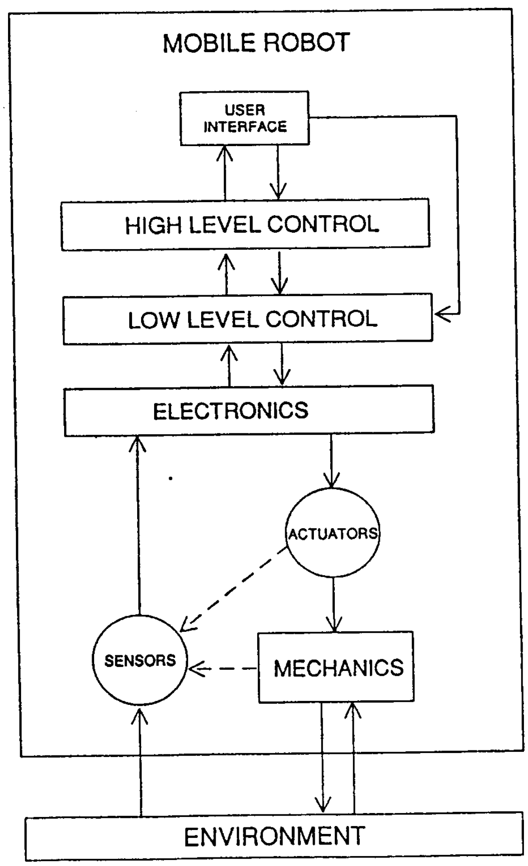

Figure 2: Logical structure

Complexity of the *user interface* can vary a lot according to the application. In very simple case it could be a on/off switch and joystick.

High level control software includes all the software, which enables autonomous operation of the mobile.

Low level control software includes driving algorithms (direct driving and curve driving) and some very fast functions like collision avoidance function.

Electronics part can be divided into digital, analog and power electronics, which are needed to convert software commands to actuator control signals and to amplify and digitize sensor signals.

Actuators can be thought as control-to-force converters. In our approach actuators are motors by default.

Mechanics can be divided into two parts. Mechanisms are driven by the controlling force and they convert the force to the movement of the mobile (i.e. wheels). The body is in the normal situation affected only by the environment (i.e. flutter and temperature).

Sensors are devices which convert environment events to electronic signals to be analyzed. At this point of our research we have been concentrated to commercial ultrasonic and infrared sensors.

In our application this division differs from physical mobile robot structure only a little. Most significant difference is that electronics and software is distributed around the system. For example physical sensors can include both electronics and software.

DESIGN CYCLE

During the design cycle total system design principles are used [1]. This means that total system is considered as one entity and when evaluating system components their affection to the operation of the total system is examined.

At first full specifications of the total system is generated. Then the system structure is designed by diving it into small submodules according to wanted actions. Interfaces between modules are defined according to their data contents instead of their functional properties. This design phase is done according to mobile robot modelling principles [2]. These principles divide the design cycle into four phases where implementation technology is not fixed until in the last phase. After this phase these submodules are divided into pieces according to realization technology. This division criteria is suitable for verification because most of commercial simulation software are limited to a specific realization technology.

Realization possibilities are software, electronics and mechanics. Sensors and actuators are special cases. In our approach they are handled as entities including software, electronics and physical sensor or actuator elements.

Division is continued until modules are so small that they are easy to test [2]. After this each submodule is designed and checked using computer aided design methods as much as possible.

VERIFICATION CYCLE

When basic modules have been designed verification cycle starts. Realization of electronics or mechanics is done only when it is absolutely necessary. Most of the testing is done by using the simulation software.

The verification cycle is done in three phases. At first each submodule is verified.

The operation of software modules is ensured with black box type testing. If errors are found they are corrected and the module is rechecked until it operates according to the specifications. The operation of electronic modules is checked with simulators and operation of mechanics is ensured with a suitable analysis software.

In the second phase these submodules are linked together and bigger entities are tested. In this phase submodules can possibly be described as black boxes but this depends highly on accuracy requirements. Until this point verification do not differ very much from the traditional software and electronics verification. Several commercial tools are available and they are quite sophisticated.

In the third phase these modules are integrated with sensors and actuators and the total system operation is verified. If design phase has been properly done good specifications of interfaces between modules are available.

Control part of the system can be integrated first. It is tested by feeding sensor data to sensor inputs and analyzing actuator outputs respectively. Depending on the reliability requirements input data can be simulated data, measured real sensor data or real sensors can be used. After passing these tests the control module can be thought as one entity having two border zones: sensor input and actuator output. That situation is illustrated in figure 3.

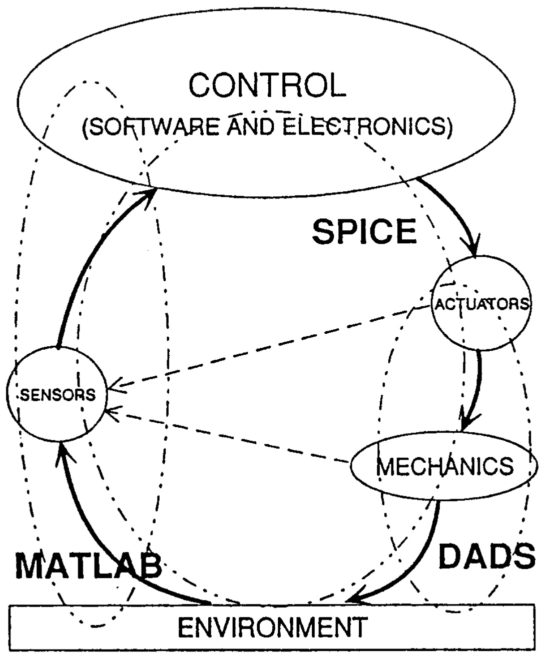

Figure 3: Tools used in integration phase

The behaviour of mechanical structure has been analyzed earlier. By modelling actuators control signals can be used to drive mechanisms and the co-operation of control, actuator and mechanics can be verified.

Most difficult situation to model and simulate is interactions between mechanics, environment and sensors. Rough simplifications must be done and the results of simulation are not very reliable.

The behaviour of the total system is very difficult to simulate but by observing the results of partial simulations carefully quite good approximation of the total system operation is achieved.

After the verification phase a prototype is built. Correct operation of the prototype is much more likely when simulation is used to test the system. If a radio link is used to transfer data between the simulation system and the mobile robot the operation of the mobile robot can be analyzed. This makes it possible to create special situations, such as sensor faults and unexpected obstacles to the mobile during normal operation.

TEST CASE

Our test case is a wheeled manipulator platform. We have been developing it for testing new ideas relating to mobile robots. During the development of the platform new design ideas have been used as much as possible.

A variety of design and simulation tools for multitechnology system subparts are available [4]. We have been evaluating a set of tools, which could satisfy our needs as good as possible.

Simulation tests are done using Sun Sparcstation™ 2 (4/75 GS). Preliminary tests were done with Sun sparcstation™ 1 (4/60 GX), which was powerful enough for simple applications.

The user interface of the wheeled platform has not yet been realized. In our test application the user interface is not very critical but on commercial applications it has a great importance.

The control system of the test mobile is very simple. As a new idea a data driven control method is tested [5]. The high level control part is realized with *PAMELA-C™* expert system shell. It offers an easy realization of rule based systems. Low level routines are written using *C*.

The verification of the software operation is done by using black box testing method. The reliability of this method depends highly on how complete test set is generated to use as input data.

Analog and power electronics needed to control two DC motors are commercial products. Digital control electronics has been designed and simulated with *WorkView™* digital electronics simulation software. The realization is based on FPGA circuits.

Mechanical structure has been designed using *Anvil 5000™* MCAD program. The geometrical data can be transferred into *DADS™* mechanism analysis software where dynamic and kinematic behaviour of the structure can be analyzed. If the strength analysis of the body were needed it could be done by applying Finite Element Method (FEM). This method is supported by *Patran™* or *Ideas™* software.

A few movement visualization tests have been done with *JC* sensor simulation software [3] to find out how a visualization module is possible to connect to our concept. The results have been promising.

We have planned to test the suitability of the simulation concept by integrating real mobile control programs with simulated electronic parts, motors and wheels. A *SPICE™* based simulation program is capable of simulating the total chain from software interface to interface between wheels and the surface. The simulation of this chain is not very fast and accurate but we presume that it would be accurate enough.

Affection of the environment has not yet been considered very carefully. It seems that the interface between mechanisms and the environment could be analyzed with *DADS™* and the results could be fed into the high level control system as operation parameters.

To simulate ultrasonic sensor operation we have developed a simple echo simulator. It calculates sensor response by using sensor model and an the environment model. This simulator is based on *MATLAB™* scientific calculation program.

In figure 3 dashed circles illustrate approximately areas where *MATLAB™*, *SPICE™* and *DADS™* are useful.

PROBLEMS

There are several problems relating to the verification of multitechnology system. When commercial software are used together some limitations must be accepted. Because these software are very seldom designed to operate with another software a perfect match with two software is not achieved.

Most difficult problems are how to synchronize simulators, how organize communication between simulators and how to decide which accuracy simulation should be done. To solve the communication problem we are going to test suitability of blackboard based communication between simulation software.

When these problems are solved the proposed design method will be useful.

BENEFITS AND DISADVANTAGES

Proposed design approach saves costs and time. Especially if several almost alike mobile robots are designed the advantages are significant. Changes to earlier version can be done easily and the operation of the new system can be verified rapidly.

There are also some disadvantages. The basic investments are quite big. Simulation software are expensive and the computer must be powerful. Model creation is difficult because it must be done carefully. A little mistake in the model may cause a major error to final test results.

CONCLUSIONS

A mobile robot development approach is presented. Total system design should be done according to sophisticated design principles. This makes it possible to use carefully choosen commercial simulation software to verify the operation of the system. At the moment the development is quite complicated because the development system is not automatic.

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