A REVIEW OF MODELING AND SIMULATION OF AUTONOMOUS MOBILE ROBOTS AIDED BY SIMULATION SOFTWARE AND PETRI NETS

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Abstract. *This work is guided by the need on development and improvement of auxiliary machines and robots in all areas of industry and agriculture and also for the requirement of new technologies which supply modeling and simulation of these robots, before its real implementation. It proposes the study and application of Petri nets and Webots*^{TM} *simulator on modeling and simulation of mobile robots and autonomous vehicles and, introduces a study of case in agriculture area, with support of Embrapa.*

Keywords*: Petri nets, precision agriculture, autonomous agricultural vehicle, modeling of mobile robots, simulation of mobile robots*

1. Introduction

Robots have been largely used for industrial and agricultural purposes due to their high mechanical structures flexibility. However, many of these machines are designed such that their control depends exclusively of a chosen language or, of a language developed specially for them (Mo and Tang, 1998). In this case, Petri nets have successful application because they are good on qualitative and quantitative performance evaluation of robotic tasks (Lima *et al.*, 1998). Moreover, as Petri nets share general properties of discrete events dynamic systems, applying these concepts to modeling robotic tasks becomes simple because each task changes to a discrete event sequence which allows the concurrency of the robotic system operations.

The use of a specific simulator that is capable to model and simulate mobile robots and their environment facilitates and increases the potential of this work, once graphical visualization becomes friendlier and simulation data allows possible variations on robot structure and control (Michel, 2004).

Mentioned study of case refers to model and simulate a Robotic Tasks Model (RTM) for an agricultural autonomous mobile robot. This work reference is part of a project that aims to model and build a robotic platform that aids the development of new technologies in autonomous navigation and data acquisition in Precision Agriculture (Sousa *et al.*, 2004).

2. Autonomous mobile robots

The autonomous mobile robot is an intelligent system, opened to its outside environment. It needs to get real time sensations in order to make decisions and to complete its driving motion tasks. These tasks may include: path tracking, turning, changing speed, among others (Wang *et al.*, 2004).

This system is usually composed of: two and / or three-dimensional vision, information processor, programming module, control module, layout module, among other equipment. Data are collected by the vision system, processed and analyzed to obtain the description of the road ahead. Based on this description, the layout module marks out the robot moving route and transfers it to the executor of the task, control module.

The obtaining of maximum system autonomy and successful completion of a given task forces a mobile robot to cope with a variety of unexpected events and / or exceptions. Therefore, special mechanisms must be provided for handling with events, such as obstacle avoidance, sensor failures, etc.

2.1. Agricultural mobile robots

Advances in mechanical design capabilities and technologies allow possibilities to realize a variety of field operations based on autonomous robotic platforms (Bak and Jakobsen, 2004). The need for such systems is driven by economic pressure on farmers and public concern about environment and work conditions. Works in precision agriculture look for development of vehicles which are able to work long hours at a slower rate and give the same, or greater, overall output while minimize conventional machines problems.

The agricultural industry has reduced its workforce and costs by introducing machinery on big farms. Tasks in agriculture fields can be divided in two categories: (1) those based on crops planted in some geometric pattern that involves driving a vehicle and (2) those based on locating objects in some area and performing operations on them (Callaghan *et al.*, 1997). Recent technological advances have caused an interest increase in autonomous farm vehicles:

- Lower costs task-independent navigation systems (e.g. GPS);
- Cheap and efficient embedded vehicle computing components (e.g. CAN);
- Availability of farm management software and tools (e.g. GIS systems) and
- Availability of methodologies on practical robotics and artificial intelligence.

Some of these technologies are being successfully applied to precision farming; robotics is also having success in farm applications.

3. Petri nets and robotics

Petri nets have general application in all robotic modeling and simulation activities, including specification, validation and code generation for robots control (Montano *et al.*, 2000). Petri net formalism can supply security requirements in real time systems. This turns the design of such systems simple and fast and reduces time and costs developments.

Petri nets have been largely used in modeling of dynamic systems, especially in automated manufacturing ones. The properties of this methodology make it qualified as a performance evaluation tool in robotic related problems.

In particular, Petri net based discrete event formalisms have been investigated as a potential mean to achieve high-level collisions avoidance, task-preserve human-intervention and runtime control. In semi-unstructured environments applications, it is difficult to predict system states since operating conditions are able to change at runtime. Petri nets can be executed to facilitate the development of on-line controllers which can generate signals at runtime. Thus, system feedback can be incorporated during execution to update its state.

According to Milutinovic and Lima (2002), a Robotic Tasks Model (RTM) is define by the 3-tuple $\tau = (R, E, A)$, where $R = \{r_1, r_2, ..., r_{n\pi}\}$ is the set of resources, $E = \{e_1, e_2, ..., e_{n\pi}\}$ is the set of events and $A = \{a_1, a_2, ..., a_{n\pi}\}$ is the set of primitive actions. A robot, an object in the environment or a primitive task represents resources of the system. It is convenient to define $\Pi = \{\pi_1, \pi_2, ..., \pi_{n\pi}\} \subset R$ as the subset of primitive tasks in R. A is partitioned in n_π subsets, because each primitive task has an associated non-empty set of primitive actions.

The RTM of a robot can be modeled using Petri nets through the establishment of a system which makes qualitative and quantitative evaluations of robot tasks. They also facilitate the development of a methodology for the implementation of a tool that coordinates the tasks. Robots control systems can be modeled with Petri nets due to their facilities and benefits with available validation techniques (Caloini and Magnani, 1998).

According to Sava and Alla (2001), hybrid systems have been studied and many different models were proposed in order to establish a mathematical system which works with their both, continuous and discrete, aspects. The functioning of Hybrids Petri nets allows the development of an algorithm for building an autonomous hybrid system. This approach uses reachability tree analysis of autonomous hybrid systems to characterize periodical functioning of associated Hybrid Petri nets.

Interpreted Petri nets can be used to model robotic tasks implementation: places represents resources and transitions are linked to events (Lima *et al.*, 1998). At design phase, places and transitions must be linked by the task designer such that robotic system goes through the desired sequence of goals that must be reached before the task goal is accomplished. All resources, required by each primitive task at each task step, also must be identified and represented by places. Each place associated to a primitive task must have two output transitions: one for a successful completion of the primitive task, another to an exit upon an error situation.

Discrete event modeling using Petri nets allows a convenient way, using graphical symbols, to express the behavior of a system that is both, asynchronous and distributed. Models must have the capacity of represent: interventions of a human operator; machine failures and interaction between multiple machines. In unstructured environments it is impossible to completely model the environment that mobile robots will navigate and work; asynchronous events require the model to incorporate sensor information during the execution of a task (Hale *et al.*, 1999). The modeling and control of robotic tasks using techniques based on discrete event Petri nets can be improved when the tasks are decomposed into sub-tasks. Petri nets are able to make each level of this hierarchy relatively simple; this can significantly reduce development and debugging time.

Petri nets also have been applied successfully in the design of protocols in communication systems (Mo and Tang, 1998). The systematic breakdown of the Petri net model for the processes at both ends of the communication parties allows more detailed design of the interacting systems which can be easily implemented as manageable software components.

Mellado and Canepa (2003) divided a multiple mobile robot system in three net types: environment net, agent net and object net, that leads to a three-level net system (3LNS). So, the environment level describes the robots environment, the agent level models the general behavior of the mobile robots and the object level represents specific features of a given robot (namely missions, tasks and roadmaps). Using this approach, obtained models become more clear and compact. Furthermore, a task model built from 3LNS constitutes an appropriate specification document for agent-based design of distributed control software.

4. Webots™

Webots™ simulation software provides a quick prototyping environment for modeling, programming and simulating mobile robots (Michel, 2004). The main features of this software are:

- Modeling and simulation of any mobile robot;
- Complete library of sensors and actuators;
- Robots programming in C, C++, Java or another software through TCP/IP;
- Transferring of controllers to real mobile robots;
- Using Open Dynamics Engine (ODE) library for accurate physics simulation;
- Creating of AVI or MPEG simulation movies;
- Examples with controller source code and
- Simulating with multi-agent systems, including global and local communication facilities.

Next figures show: stages of development of a robot simulation (Figure 1), world and robot graphical window (Figure 2) and the scene tree window (Figure 3).

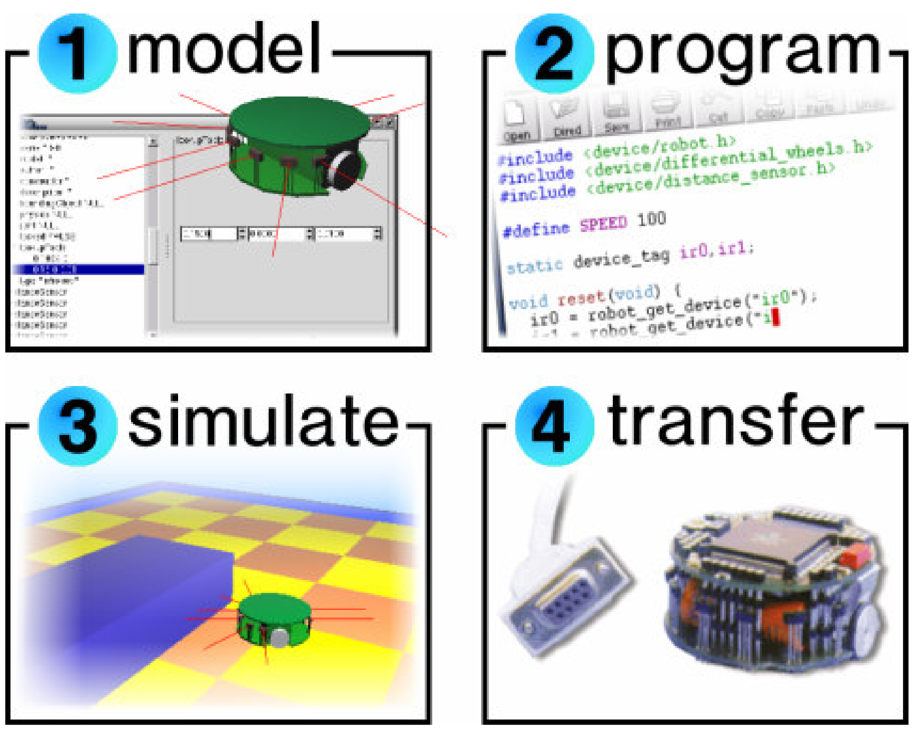

Figure 1 - Stages of development of a robot simulation (Michel, 2004)

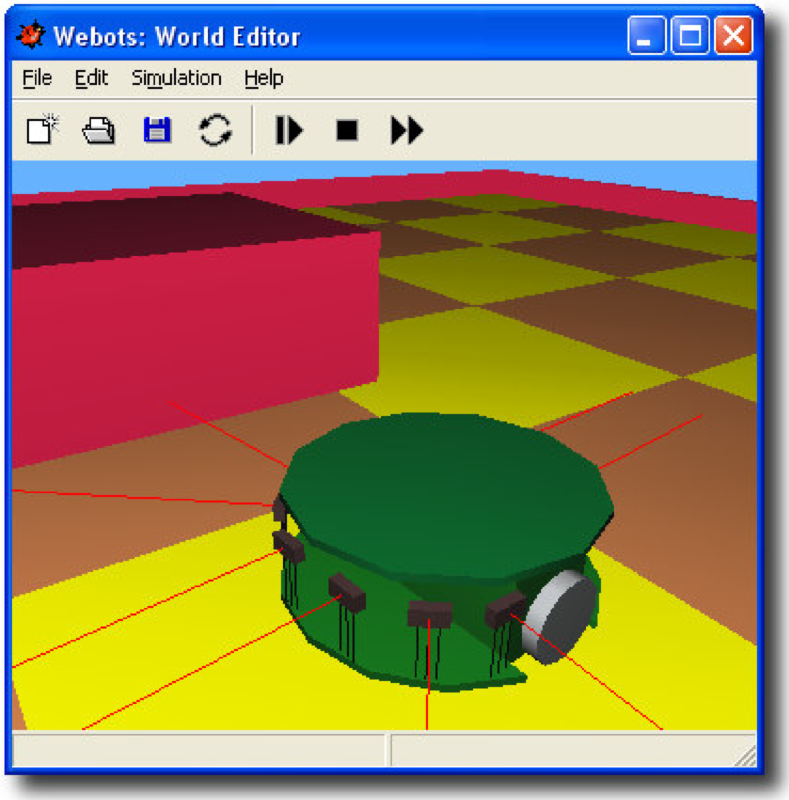

Figure 2 - Visualization of a robot model and its world (Michel, 2004)

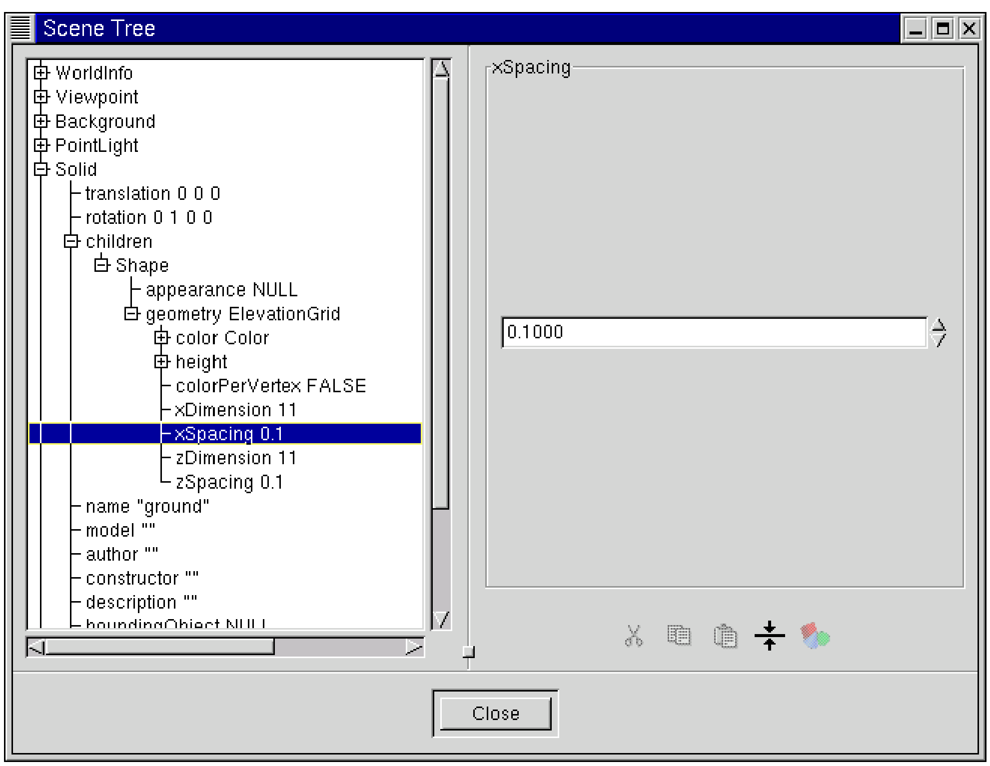

Figure 3 - Example of a scene tree window (Michel, 2004)

An interesting characteristic of Webots™ is that one can transfer controllers programming to a brand new robot (besides Khepera®, LEGO® and others): the software user guide explains how to build a cross-compilation system for this purpose.

5. Study of case proposal

Robots built for any purposes have to be simulated first, in order to avoid or minimize problems with driving motion, controlling, using of sensors and actuators, completion of tasks, acquisition of data and information, among others. The simulation of this kind of system involves, at first time, building a model of the robot and, if it is possible, a model of the environment where the robot will move and work.

Thus, besides technical and mathematical formalism, especially on robotic part, graphical interface of simulation must be very friendly and should contain some mechanisms for the designers to on-line view and follow all runtime changes in system.

As shown in Figure 4, the work consists in: defining a robot model and its RTM; modeling the RTM through Petri nets (which gives mathematical formalism and validation of the model); building the robot model with RTM data in Webots™ (which allows graphical visualization and step-by-step simulation) and, simulating both models, graphical and Petri net based, in order to compare results, make evaluations and improve the model.

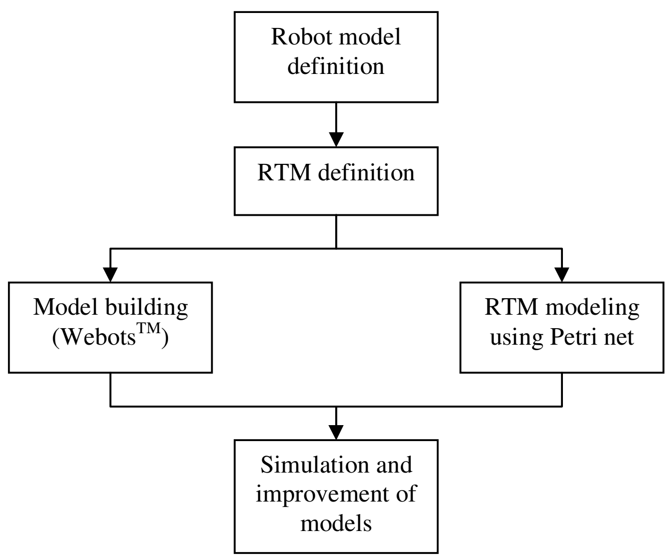

Figure 4 - Work scheme

Finding optimal robot and RTM models gives computational structure and basis for implementing controllers on a real robot. This implementation will occur in a robotic platform which has the aim of support the development of new technologies in autonomous navigation and data acquisition in Precision Agriculture.

6. Discussions and conclusions

Accomplished studies show that it is possible and coherent modeling mobile robots tasks through Petri nets. Also, there are a variety of available programs to simulate and evaluate all types of Petri nets what is very useful to validate the model.

On the other hand, mobile robot simulation software turns graphical visualization friendly and produces easier and faster on-line views of the system.

Thus, if mathematical formalism and technical validation could be obtained and preserved in an optimal robot-environment model, it is expected that implementing data recovered from simulations, in a real system, has good results.

7. Acknowledgements

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