Towards the autonomous navigation of intelligent robots for risky interventions

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1 Introduction

In the course of the ViewFinder project, two robotics teams (RMS and PIAP) are working on the development of an intelligent autonomous mobile robot. The first question one should pose in this context is: ”What is an intelligent autonomous mobile robot or what does it do?” This is of course largely task-dependent, yet there are some capabilities which should necessarily be present.

First, to navigate autonomously in an unknown environment, the robot needs to dispose of a means to detect and avoid obstacles. Numerous sensors exist which can detect obstacles in the path of the robot. These include ultrasound sensors, laser range finders, infrared sensors, vision, etc.

Next, the robot needs some degree of self-consciousness, meaning that it needs to be able to infer its current status in relation to the outside world from its sensor readings. This problem is also referred to as the Simultaneous Localization and Mapping (SLAM) problem. Classical SLAM solving techniques use input data from laser range scanners or ultrasound sensors, yet also visual data can be used.

Third, the robot must dispose of some sort of ”intelligence” to execute the tasks or objectives it has been given. These objectives can be multiple and may be in contradiction with one another.

This paper describes and compares the approaches proposed to solve these issues in the framework of the ViewFinder project for two different robot platforms: the outdoor RMS Robudem robot which uses behavior based reasoning and the indoor ”red” PIAP robot which relies on a vision-based behavior. It is shown how the different constraints for both robots lead to a different design of the robot architectures. Also, the cooperation between the red robot and the tele-operated Inspector robot is presented. The main task of the red robot is to enhance the operational capabilities of the Inspector robot during risky missions. As an example, the operator would be able to observe the arm of the Inspector from the red robots’ perspective, hereby facilitating the tele-operation task on the Inspector and rendering the mission objective easier obtainable. Using intelligent computing and vision based collaboration of the robots, new capabilities of tele-operation of the Inspector robot can be achieved.

The remaining of this paper is organized as follows: in section 2 the behavior-based control architecture of the RMS Robudem robot is explained. Section 3 details the control architecture of the PIAP red robot and describes its collaboration with the Inspector robot. Finally, the conclusions section lists the main differences between the presented control technologies and explains the different design choices taking into account the robot missions.

Figure 1: The outdoor Robudem robot.

2 Behavior-based control of the Robudem outdoor robot

2.1 Goal and problem statement

The goal of this research project is to prepare the Robudem, an outdoor mobile robot platform as shown on Figure 1, for a crisis management application. In this setup, the robot assists human fire fighters and other members of crisis management units. The main task for the robot is information retrieval: on-board sensors deliver information about chemical contamination, structural degradation or human presence on the incident site. To this extent, the Robudem robot will be equipped with a number of sensors. The abundance of information coming from all these sensors calls for an intelligent data management system on the robot and in the base station. In this paper, we concentrate on the information flow within the robot itself.
In order not to overload the human crisis managers too much with robot control tasks, the Robudem must be able to operate semi-autonomously in the crisis site. This means the robot needs to be able to navigate by itself in a complex and hazardous environment. To this extent, an intelligent autonomous control architecture takes into account the information of all sensors. The control architecture describes the strategy to combine the three main capabilities of an intelligent mobile agent: sensing, reasoning (intelligence) and actuation. These three capabilities have to be integrated in a coherent framework in order for the mobile agent to execute a set of given tasks or ”objectives” adequately. These objectives can be multiple and may be in contradiction with one another. Therefore, also a technique to solve the multi-objective decision making problem is required.

2.2 State of the art

An autonomous mobile robot must be self-reliant to operate in complex, partially known and challenging environments using its limited physical and computational resources. Its control system must ensure in real time that the robot will achieve its tasks despite all these constraints. [5]
One of the first robot control architectures was the Sense Model Plan Act (SMPA) paradigm. The primary drawback of this approach is that the series of stages through which all sensor data must pass places an unavoidable delay in the loop between sensing and action. To counter this drawback, alternatives, such as the behavior-based approach, were proposed.
In behavior-based control, the control of a robot is shared between a set of purposive perception-action units, called behaviors.[6] In the behavior-based spirit a complex control problem is divided into a set of simpler control problems that collectively solve the original complex control problem. Based on selective sensory information, each behavior produces immediate reactions to control the robot with respect to a particular objective, a narrow aspect of the robot’s overall task such as obstacle avoidance or wall following.
Behaviors with different and possibly incommensurable objectives may produce conflicting actions that are seemingly

irreconcilable. Thus a major issue in the design of behavior-based control systems is the formulation of effective mechanisms for coordination of the behaviors' activities into strategies for rational and coherent behavior. This is known as the behavior fusion or action selection problem. Numerous action selection mechanisms have been proposed over the last decade; a qualitative overview can be found in [4]. The behavior-based controller presented here uses a mix of goal programming and statistical reasoning to determine the activity level of each behavior.

2.3 The behavior-based framework

Figure 2 shows the proposed control architecture for the Robudem robot. It lists all modules which are related to robot control and indicates their relationships using arrows. Color coding was used to enhance the readability of the scheme. Following this color scheme, sensors appear green, spatial processing (mapping) modules appear violet, visual processing modules are shown red, behaviors appear orange and robot control and actuation modules are shown in gray.
From a global point of view, we can distinguish 2 main components in this framework.

- A Visual Simultaneous Localization and Mapping processor
- A Behavior Fusion processor

The Visual Simultaneous Localization and Mapping (VSLAM) processor takes as input information coming from different sensors: odometry, GPS, prior map data (if present) and a color camera. From this information, the VSLAM module builds a map of the environment while localizing itself in that map.
The second main component is the Behavior Fusion processor, which takes as input the objective functions of the different behaviors and fuses this information to come to one consistent and globally optimal command to be executed by the robot. These objective functions are multi-dimensional functions which reflect the preference of each behavior for each type of possible actions.
We will now discuss the different behaviors which are foreseen for the Robudem robot.
A first application is simple tele-operation of the Robudem robot. To frame this into a behavior-based context, a *Joystick* sensor is linked to a *ObeyJoystickCommand* behavior which tries to steer the robot into the direction suggested by the human operating the joystick.
For autonomy, there are a number of behaviors which have the task of keeping the robot from bumping into obstacles. As the Robudem is equipped with multiple sensors with very different spectral properties, various types obstacles can be perceived:

- The sonar sensors detect obstacles using ultrasound ranging, allowing a behavior *AvoidObstaclesUsingSonar* to steer the robot away from obstacles.
- A stereo vision camera uses dense feature matching to obtain a quasi-dense depth map which allows the behavior *AvoidObstaclesUsingStereo* to set up an objective function to steer the robot away from nearby objects.
- A chemical sensor will be installed on the robot. This sensor is capable of detecting chemical contaminants. A local map of the chemical contamination in the zone around the robot will be built using this data. This information will allow a behavior *AvoidChemicals* to steer the robot away from danger zones.
- A thermal sensor will be installed on the robot. A local map of the temperature in the zone around the robot will be built using this data. This information will allow a behavior *AvoidHotZones* to steer the robot away from danger zones.
- The environmental map calculated during Visual Simultaneous Localization and Mapping is used to steer the robot away from obstacles on the map by a behavior *AvoidObstaclesUsingSLAM*.

The set of behaviors presented above have the task of assuring robot safety by not letting it bump into obstacles or by not allowing it to traverse hazardous zones. Another set of goal-oriented behaviors assures that the robot navigates to certain goals:

- The behavior *MaximizeTerrainKnowledge* takes as input the environmental map calculated during Visual Simultaneous Localization and tries to steer the robot into the direction of any unmapped areas, hereby completing the map.

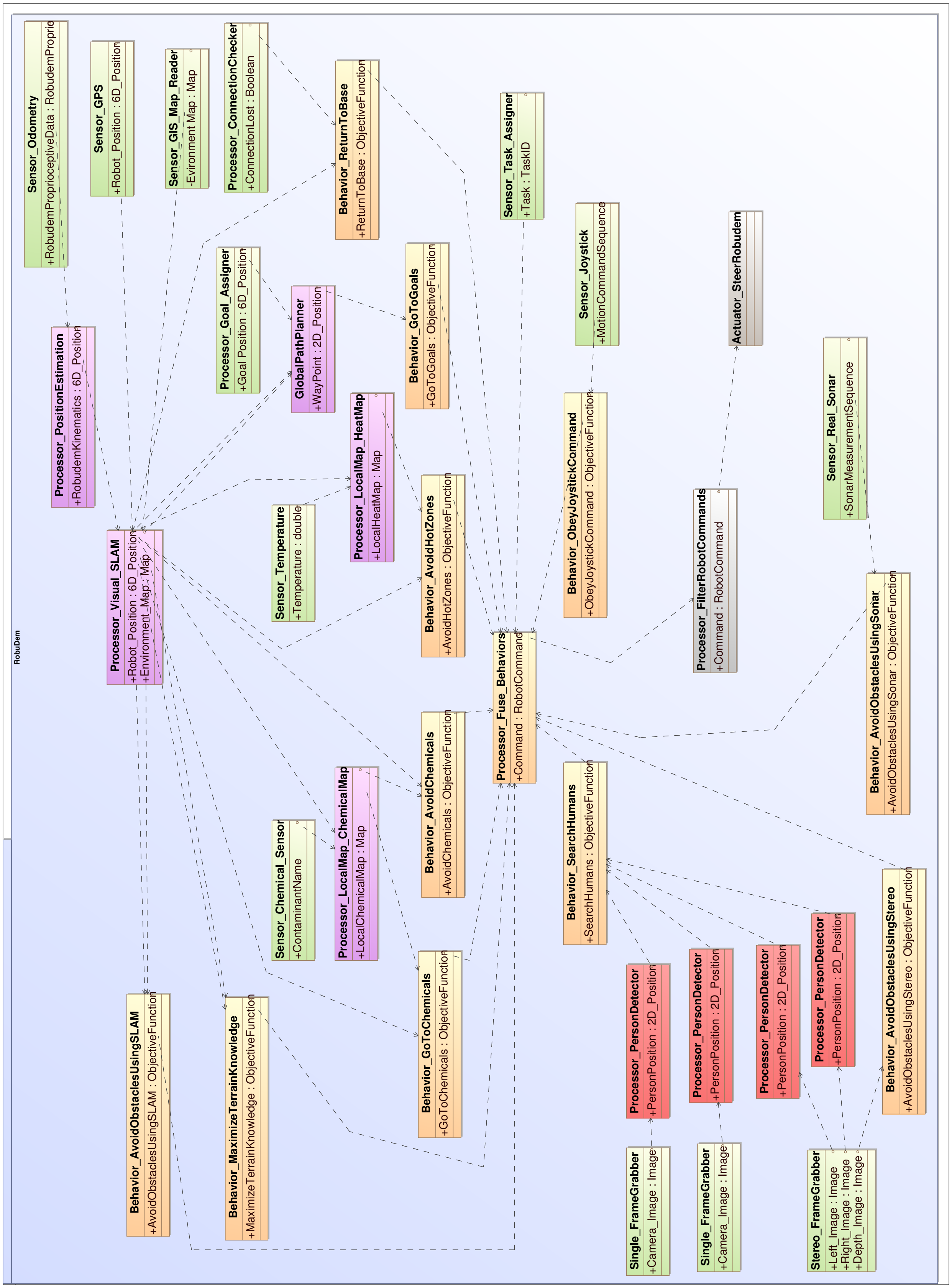

Figure 2: The control architecture for the Robudem robot. Note that - in order to preserve the readability - this figure only lists the modules which are related to robot control, not those which are related to user interfacing. Detailed explication of all these modules and the framework can be found in section 2.

Figure 3: The indoor ATRV-Jr robot.

- The behavior *GoToChemicals* takes as input the local chemical map and steers the robot into the direction of the most chemical contamination. This behavior can be very useful when trying to locate the source of a chemical leak.
- A *ConnectionChecker* sensor constantly checks whether the wireless network link with the robot base station hasn't been compromised. If the connection fails, the behavior *ReturnToBase* tries to steer the robot back into the direction of the base station, hoping that the network link be restored.
- A global path planner takes as input a list of goal positions given by a human operator and, using the environmental map and robot position estimated through VSLAM, breaks down these goals into intermediate waypoints. A *GoToGoals* behavior then tries to steer the robot into the direction of these waypoints.

More ambitious tasks and objectives to be executed by the robot are also possible. Using the input of multiple on-board cameras, it is possible using computer vision to search for the presence of humans (victims) in the camera images. Using this information, a *SearchHumans* behavior can then decide on a direction to steer the robot into in order to acquire more information or a better view on the human.

3 Control of the PIAP red indoor robot

The goal of the development of the intelligent autonomous mobile robot ATRV-Jr, as shown on Figure 3 is to achieve intelligent control by concentrating on the following research topics damage management, adaptability, working with noisy information, parallel processing with low level energy consumption.

Damage management is based on the implementation of robust algorithms and duplication of the functionalities. We use behavior based obstacle avoidance algorithms which are robust in the case of noisy data. Resistance to noisy data is required, as noisy data is commonly generated by improper functioning of the ultrasonic sensors. A SLAM algorithm fuses odometry and sonar data. A match scanning algorithm based on input from the laser range finder LMS SICK 221 also provides positioning data. Therefore the general control unit has 2 inputs of positioning data from the self local localization algorithms. Each device has its own control unit which serves its' functionalities. In case of hardware damage, the system is able to reconfigure and fall back to the best configuration to achieve the goal. Each device such as odometry, compass, sonars, video camera and other sensors has an associated control program. This way, the control system is conscious of the usable functionalities of the mobile platform.

Adaptability is obtained by the implementation of a modified robust algorithm based on artificial neural networks: fuzzy ARTMAP. Due to these modifications a real-time response of the network is possible in real environments [1]. The time needed for decision making determines the quality of the system and should be as short as possible, as a collision free motion path must also be executed as fast as possible in critical conditions. The general idea of the fuzzy ARTMAP was described in [3]. The fuzzy sets themselves are used to code the information from ultrasonic sensors. The system is able to learn new associations between the set of coded ultrasonic sensor results into the set of coded values of motors velocities. This algorithm has high generalization, and adaptability.

Dealing with noisy information is achieved by using visual processing, tacit knowledge construction of the environment and self localization algorithms. Noise removal from image operations can be implemented as Cellular Neural

Network (CNN) [2]. CNN's are often used as fast image processors because they are highly efficient in some applications such as noise removal, edge and corner detection, hole filing and operations of mathematical morphology. The tacit knowledge construction of the environment is achieved by the fuzzy ARTMAP neural network. Self localization algorithm is based on match scanning.

Parallel processing with low level energy consumption is obtained by using CORBA (Common Object Request Broker Architecture). CORBA is a mechanism in software for normalizing the method-call semantics between application objects that reside either in the same address space or remote address space. Each server associated with appropriate device runs independent from others. Therefore, each program from the control unit works in parallel. Using the CORBA mechanism as a framework of communication between sensors and the main computer of the robot allows for fast reconfiguration of sources of information about the environment. This technology allows to introduce a small multi-agent system on the board of the robot, by creating many independent data servers and data processors.

4 Conclusion

Two intelligent robot control architectures have been proposed. The control architecture being developed for the outdoor Robudem robot uses behavior-based reasoning to provide a wide range of functionality, making the robot able to traverse complex outdoor terrain semi-autonomously and assist human crisis managers in better assessing a crisis situation.

The control architecture for the indoor ATRV-Jr enables the robot to avoid obstacles, to follow a wall, to follow a predefined path, to localize itself, to construct a local map of the environment and to reconfigure itself. Ass added value the ATRV-Jr can collaborate with a tele-operated Inspector robot by transmitting a video feed of the other robot.

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