Autonomous Mobile Robotics
Proposal for a Course Structure

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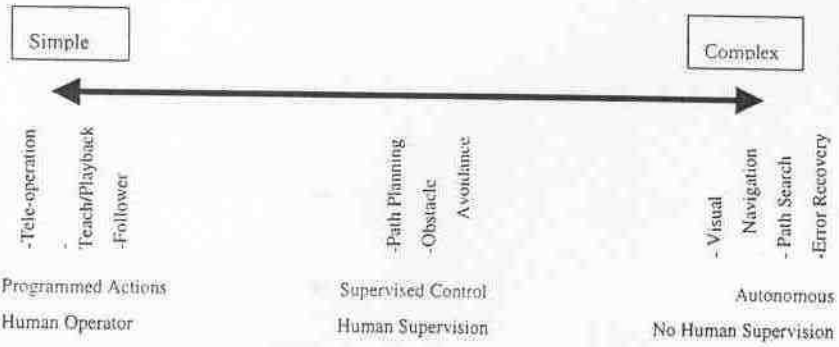
Abstract. *Mobile robotics is a multidisciplinary area involving different aspects of engineering and computer science. Mobile robotics is a very active domain, with different interesting scientific topics and it is difficult to obtain a consensus concerning the set of main topics for an educational course on the subject. This article purposes a structure for a mobile robotics course, with emphasis on sensor processing to reach more flexible and autonomous mobile robotics platforms. The article describes the main subjects, the final goals, seminars and the experimental work, to be presented along the course. The course was designed for Master students with background on Electrical Engineering or Computer Science.*

1. INTRODUCTION

A mobile robot is a machine composed by mechanical links, electric devices, electric circuits, sensors and actuators. This machine is able to interfere in the world and its activity, can be controlled by humans or to be autonomous. The autonomy concept, when applied to mobile robotics systems, defines a machine (vehicle) able to perform "intelligent" actions without human intervention. The degree of autonomy depends on the degree of difficulties and unexpected situations that the machine can surpass, without human intervention. The diagram clarifies better this concept.



The set of subjects necessary to manage during the design process of these machines is quite large and detailed. However, one topic that appears to be crucial to increase mobile robot's autonomy is the control of robot's activity based on the results from the processing of sensor information. Algorithms for sensorial data interpretation and sensor data fusion, gives the support for the development of better control algorithms and

increasing of autonomy. As summary, an educational course, with emphasis on "mobile robotics autonomy", must have topics within the fields of sensor data processing, data estimation and control.

The motivations to developed machines with more autonomy are several and they include economical and safety reasons. This justifies an educational course to promote the development of new applications of mobile robots.

The next section describes the context and main goals of the proposed course. The scientific subjects organized as modules are described in section 4. That section describes laboratorial activities and activities related with journal articles' analysis. A proposal for a scheduling of classes and activities and a short summary concludes the two last sections of the article.

2. CONTEXT AND MAIN GOALS

Mobile robotics is a multidisciplinary area involving different aspects of engineering and computer science. Actually, mobile robotics is a very active domain, with different interesting scientific topics, and it is difficult to obtain a consensus concerning the set of main topics for an educational course on the subject. This article addresses a structure for a mobile robotics course, with emphasis on sensor processing and mobile robotics autonomy. The article describes the main subjects, the final goals, seminars and the experimental work of the course. The course has been attended by Master students from the Electrical Engineering Department of the University of Coimbra since 1999, and the experience shows that gives good training on experimental mobile robotics field.

The applications of mobile robot systems are characterized by specific properties of the environment or tasks. Some of these properties are:

- The environment is dangerous for humans.
- The environment is remote and sending a human is costly or impossible.
- The task is very demanding for humans (substantial human effort, needs high performance or needs high quality).

Technical solutions have a crucial impact on the final decision on the implementation a robotic solution for a specific task and often they collide with economical decisions. The correct use of actual technologies and good engineering practice is fundamental to proceed with a project and obtain success.

This course tries to cope with this situation, giving the necessary training to achieve these goals. During the course, the students will contact with actual technologies for sensing, actuators, locomotion and control mobile robotics. These subjects are complemented with the scientific background, necessary to encourage the development of algorithms, techniques and new applications for mobile robotics, based on these technologies.

After finishing the course, the students will have the knowledge about the current techniques and technologies for mobile robotics. It is expected that the students will be able to analyze and criticize solutions for improvement of robots autonomy and they will be able to participate on the development of new applications for mobile robotics.

3. SUBJECTS AND MODULES

The course has a structure with six modules or chapters and it tries to cover a set of fundamental subjects on mobile robotics domain (see figure below).

Chapter 1 - State-of-Art on Autonomous Mobile Robots

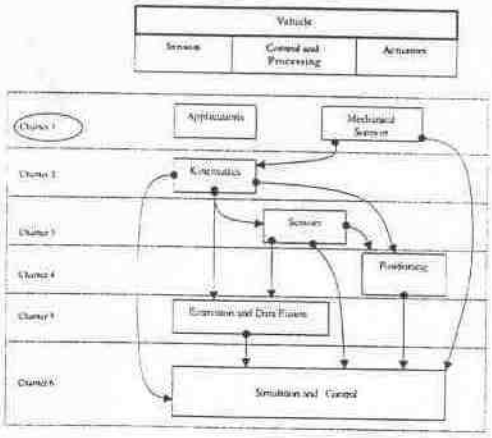
Chapter 2 – Kinematics and Dynamics

Chapters 3 – Sensors and Perception

Chapter 4 - Positioning and Sensor Measurements

Chapter 5 – Estimation and Sensor Data Fusion

Chapter 6 – Control and Simulation



The course's main bibliography includes the subjects described in [9], [10], [14], [28], [29] and [30].

The course activities are divided on classes (oral expositions), case studies (article's discussions) and practical activities in the laboratories.

The first chapter's goal is to introduce the engineering domain, giving a brief overview about the different subjects, definitions and technologies. The chapter

finalizes with examples of different applications and some open issues on mobile robotics. The chapter 1 outline is:

Chapter 1. Introduction to the Autonomous Robots
- 1. Definitions
- 2. *Robots* Classification
- 3. Goals and Applications
- 4. Examples of *robots*
- 5. Different Robot's Sub-Systems
- 6. Autonomy and Cycle Perception-Processing-Action
- 7. Different Levels of Autonomy
- 8. Architecture of a Robot: A Hierarchical Model
- 9. Main Issues in Robotics

The subjects described in this chapter are also described in [9], [10], [8], [11] and [5].

The chapter 2 gives the necessary background on kinematics and dynamics of mobile robotics. These subjects are crucial for robot's modeling, for motion analysis and interaction of the robot and the physical world. Kinematics modeling is applied to robots' joints and to mechanical structures for active sensor devices such as: laser range finders, active vision systems. Different kinematic modeling examples are described during this chapter. The chapter 1 outline is:

Chapter 2. Kinematics and Dynamics
- 1. Kinematics Fundamentals
  - 1.1 Fundamentals
  - 1.2 Rotations
  - 1.3 Homogeneous Coordinates
- 2. Kinematics of Mechanical Systems
  - 2.1 Direct Kinematics
  - 2.2 Inverse Kinematics
  - 2.3 Differential Kinematics
- 3. Examples of Kinematics' Models
  - 3.1 Coordinates and References for a Car Like robot
  - 3.2 Kinematics of an active vision system

The subjects described in this chapter are also described in [10], [11] and [12].

The chapter 3 main goals are the description of sensors and technologies for perception and map building. Autonomy is dependent of results from sensor information processing and sensor technologies available. These subjects are the important part for improve and achieve high levels of autonomy. Different sensor technologies, namely vision, are described, and they include algorithms to process volumetric data. The chapter 3 outline is:

Chapter 3. Sensors and Perception
- 1. Radiant Sensors
  - 1.1 Classifications and Taxonomy
  - 1.2 Distance measurement techniques
  - 1.3 Sensors
- 2. Sensors for Perception
  - 2.1 Laser telemetry
  - 2.2 Ultrasound telemetry
  - 2.3 Cameras
  - 2.4 Vision Systems
- 3. Algorithms for Visual Perception
  - 3.1 Stereovision
  - 3.2 Active Vision Systems
  - 3.3 Volumetric Image Processing

The subjects described in this chapter are also described in [9], [30], [18] and [19].

Robot positioning is necessary for navigation of mobile robots and the chapter 4 gives a description of some sensors and technologies for positioning. Basic and fundamental techniques are described, including techniques based on radiant and non-radiant sensors. The chapter 4 outline is:

Chapter 4. Positioning and Sensor Measurements
- 1. Fundamentals for Positioning Techniques
  - 1.1 Fundamentals
  - 1.2 Coordinate Systems
  - 1.3 Inertial References
- 2. Position Estimation Techniques
  - 2.1 Triangulation
  - 2.2 Dead-reckoning
  - 2.3 Errors and upper bounds
  - 2.4 Examples
- 3. Sensors for Position Estimation
  - 3.1 Inertial sensors
  - 3.2 Compass
  - 3.3 Gyro meters
- 4. Inertial Navigation Systems
  - 4.1 Introduction
  - 4.2 Mechanization
  - 4.4 Technologies
- 5. Satellite Navigation Systems (GPS)
  - 5.1 Introduction
  - 5.2 Operation
  - 5.5 Precision

The subjects described in this chapter are also described in [9], [28], [31] and [32].

An important issue in robotics is the processing techniques to combine different sensing modalities. Another important issue is the combination of several sensors' readings, to estimate physical parameters from the robot and its surroundings. The chapter 5 is the module where methodologies and techniques for parameter estimation and information combination are described. The chapter 5 outline is:

Chapter 5. Estimation and Sensor Data Fusion
- 1. Fundamentals
  - 1.1 Random variables
  - 1.2 Random Signals
  - 1.3 Probabilistic Distributions
- 2. Uncertainty and Data Fusion
  - 2.1 Uncertainty
  - 2.2 Least Square Techniques and Probabilistic Models
  - 2.3 Batch and Recursive Combination
- 3. Filtering and Estimation
  - 3.1 Introduction to optimal estimation
  - 3.2 Kalman Filtering
  - 3.3 Extended Kalman Filtering
- 4. Bayes Estimation

3.1 Fundamentals of Bayes Estimation
3.2 Sequential Combination

Some of the subjects described in this chapter are also described in [14], [15], [16] and [17].

Basic control techniques, using case studies, are described in this chapter. Simulation is also an essential tool for the development of control systems and development of mobile robot equipment. This chapter describes, briefly, different simulation tools and techniques used during the mobile robotics development and research. The chapter 6 outline is:

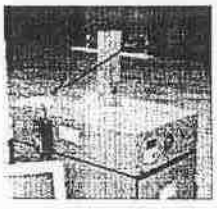
Chapter 6. Control and Simulation
1. Simulators and Development Tools
1.1 Introduction
1.2 Simulation and Models
1.3 Representation Structures
1.4 Simulation of Radiant Sensors
1.5 Surfaces and Terrain Modeling
1.6 Errors and Noise
2. Case Study: Control of four wheels Car
2.1 Single track model (2 wheels)
2.2 Model Linearization
2.3 Different Control Structures
2.4 Navigation and Steering Control

Some of the subjects described in this chapter are also described in [29].

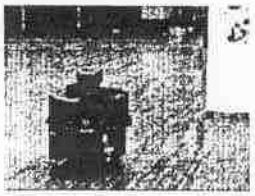
3.1. Laboratorial Activities

The laboratorial activities are one important part in the course, since they give opportunity to students to deal with common problems with robotics experiments.

The activities in the laboratory are defined in 3 specific domains: (i) obstacle detection, (ii) map building, and (iii) positioning. In all of them, the students must run a mobile platform (see figures) and develop some programming. The laboratory assignments are:



(i) Obstacle Detection from Stereo Disparity



(ii) 2D Mapping with Occupancy grids

(iii) Inertial Sensing and GPS positioning

3.2. Articles and Case Studies

The students are responsible by the exposition of the case studies and, based on a set of leading articles published in recognized technical journals or conferences. The exposition is similar to a small workshop and must be attended by all students. The section is organized in the end of the course period, and each student (or a student's group) has some amount of time (typically 20 minutes) for an oral exposition of the analysis performed in one article. A text summary with his analysis is distributed to the other colleagues, some days before the oral exposition.

3.3. Calendar

The course activities can be spread within 30 hours (1 semester) and the course activities are divided on classes (oral expositions), case studies (article's discussions) and practical activities in the laboratories.

4. SUMMARY

The article described a structure for a mobile robotics course, with emphasis on sensor processing and mobile robotics autonomy. The article described the main subjects, the final goals and the experimental work to be presented along a Master course. The course was designed to be attended by Master students with Electrical Engineering or Computer Science background.

Prerequisites to attend this course include a good background in Linear Algebra, Statistics and experience in Computer Programming (Matlab and C). The described course is, since two years ago, an active course of the Master curricula of the Electrical

Engineering Department of the University of Coimbra, Portugal [36]. The course could be customized for students with different backgrounds, and for different levels of studies: technological oriented or more theoretical oriented.

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