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Review on Land-Based Wheeled Robots

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Abstract. This paper presents an overview of the state of art of mobile robots presenting aspects of their current level of sophistication, fields mobile robots are being presently used, the future application and scope of mobile robots. Classifying the primary research topics of multi-robot systems into seven major categories (Biological inspirations, architecture, localization/mapping/exploration, object transport and manipulation, motion co-ordination, reconfigurable and learning robot systems, vision), we discuss the current state of research in these areas. An attempt to cover the points for which a general agreement has emerged within the scientific domain, are then presented, followed by a discussion of alternative approaches and currently unsolved problems. This paper also reviews the most relevant literature and previous research activity regarding mobile robotics. We conclude by identifying more topics of scientific consensus, open research issues and a discussion of some application areas where mobile robots could be used with existing technology.

1 Introduction

Literature [1] defines Mobile Robots as robots that can move from one place to another autonomously, that is, without assistance from external human operators. The field of autonomous mobile robots can be considered immature from research point of view. Unlike a fix based industrial robot [2-5], a mobile robot has a greater freedom for movement. The perks of mobile robots over conventional fixed/industrial robots are

i) Ability to operate in a larger workspace.
ii) Ability to explore unknown environments.
iii) Ability to co-ordinate with other robot/ group of robots to perform a single integrated task.

Due to such abilities mobile robots can substitute humans in many fields by carrying out the functions of exploration, patrolling, surveillance, home appliances (e.g. lawn mower and floor cleaner), butler etc. [1].There has been an explosive growth in the research of mobile robots in the last decade. Such mobile robots can be broadly classified into three categories based on environments they operate in a] Land/ ground based robots b] aquatic/ underwater robots c] aerial robots [6].

We would be discussing only about the type(a)- 'Land based mobile robots' in this paper. As they are designed to operate in unknown environments, mobile robots demand a much higher level of intelligence than the conventional industrial robots. This is now possible due to advancements in silicon technology and computing power. A field defined as cooperative mobile robotics has also emerged in the recent years which uses a combination of a number of mobile robots in coordination to

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execute various tasks. Most of the work in cooperative mobile robotics began after the introduction of the new robotics paradigm of behavior based control [4]. Many cooperative robotics researchers find examining the social characteristics of insects and animals helpful while designing such cooperative mobile robots. Mobile robots find a huge application in military and defense. They are used for various purposes such as surveillance in enemy territory, mine detection and defusing, hostage rescue scenarios and as a substitute for soldiers.

A great segment of research in mobile robotics is dedicated to development of architectures, task planning capabilities and control. Developing an architectural structure for multi-robot systems has is being focused upon greatly [7].

Localization, Mapping and Exploration are classified as the major primary operations of a mobile robot (Land). The single and multi- robot approach to localization, mapping and exploration can be described using categories based on use of landmarks, scan-matching, use of graphs, range sensors and vision sensors [8]. One widely discussed question about single and multiple mobile robot systems is the effectiveness of multi-robot teams over single mobile robot. This question is currently being taken into study but much remains to be determined for the variety of approaches and methods for localization, mapping and exploration.

Some of the earlier work in robotics which was focused on reconfigurable distributed systems is now being researched further with an aim to achieve function from shape, allowing individual modules, or robots, to connect and re-connect in various ways to generate a desired shape to a particular operation. Theoretically speaking, these systems have a capability of showing great robustness, versatility, and even self-repair [8].

Each and every aspect of the topic would be broadly analyzed in the upcoming sections.

2 Types of Mobile Robots

The types of robots possible are unlimited, though we classify the mobile robots broadly into these categories:

1. Land-based wheeled robot
2. Land-based tracked robot
3. Land-based legged robot
4. Air-based: Plane, helicopter, quadcopter, drones
5. Water-based: Boat, submarine
6. Hybrid/combination Robot
7. Stationary robot (arm/manipulator)

Since we are only discussing about the Land-based robots, we will study only the first three categories in detail.

3 Land-based wheeled robots

The Wheeled mobile robots which operate on land/surface [9, 10] can be broadly classified into two categories

i) robots with locally restricted mobility- (i.e. with Non-holonomic constraints)

ii) robots with full mobility - (Omni-directional robots)

Mobile robot subsystems are: Locomotion [11] (concerning how the robot moves through the environment), Sensing (concerning how the robot measures properties of itself and its environment), Control (concerning how a robot generates physical actions), Reasoning (concerning how the robot maps measurements into action), and Communications (concerning how the robot communicates with other robots or with an outside operator).

Operating Environments: An operating environment for a robot falls into one of these three categories.

- •Structured Environments: The robot has a complete knowledge of the environment allowing an offline planning of the motion (due to availability of a map possibly acquired by the robot sensors in an exploratory phase).
- •Semi-structured Environments: The robot has incomplete knowledge of the environment thus allowing motion global planning but local flexibility has to be provided due to the presence of dynamic obstacles.
- •Unstructured Environments: The robot has a very limited environmental knowledge and has to face a wide variety of obstacles/situations [12].

The structured/semi-structured environments are also termed as Indoor (2-D) environments while the unstructured environments are termed as Outdoor (3-D) environments.

A basic motion problem for a land based wheeled robot is to plan its path through static and dynamic objects and to reach its destination [13]. A user may program the robot to travel via various paths such as the least time path or the least cost path. Many times there are multiple mobile robots involved in the task to be performed and they need to co-ordinate and work in unison to complete the task with a higher efficiency [14, 15].

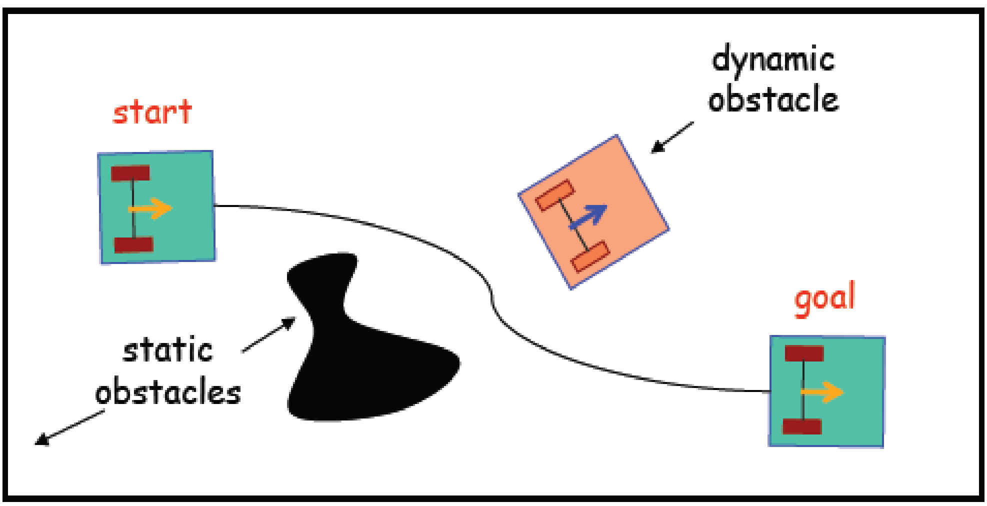

Figure 1. Basic motion problem.

The following are the elementary motion tasks executed by a wheeled robot

- ➢ Point to Point motion
- ➢ Path following
- ➢ Trajectory tracking
- ➢ Purely reactive (local) motion - [Obstacle avoidance, wall following, target tracking]

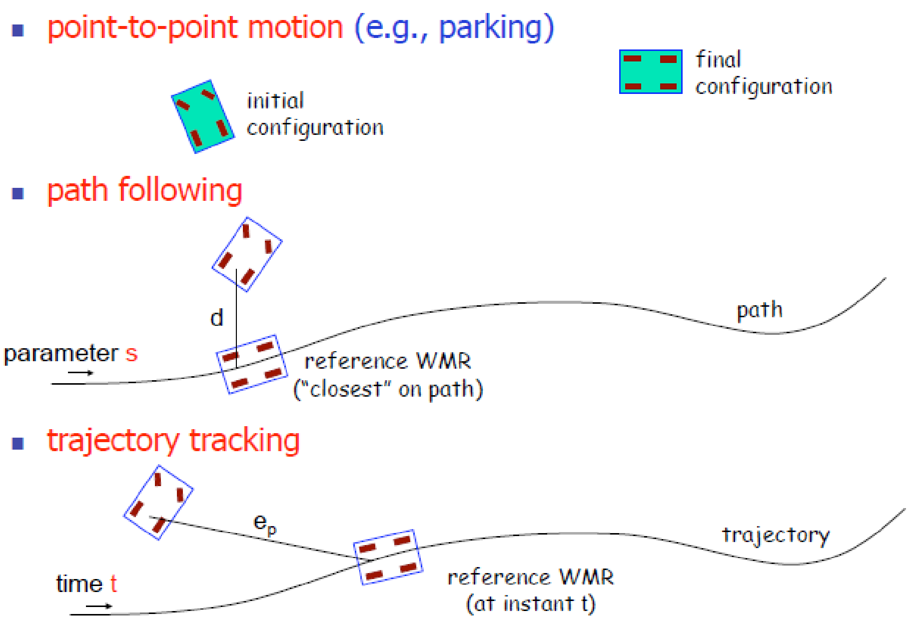

Figure 2. Types of motion.

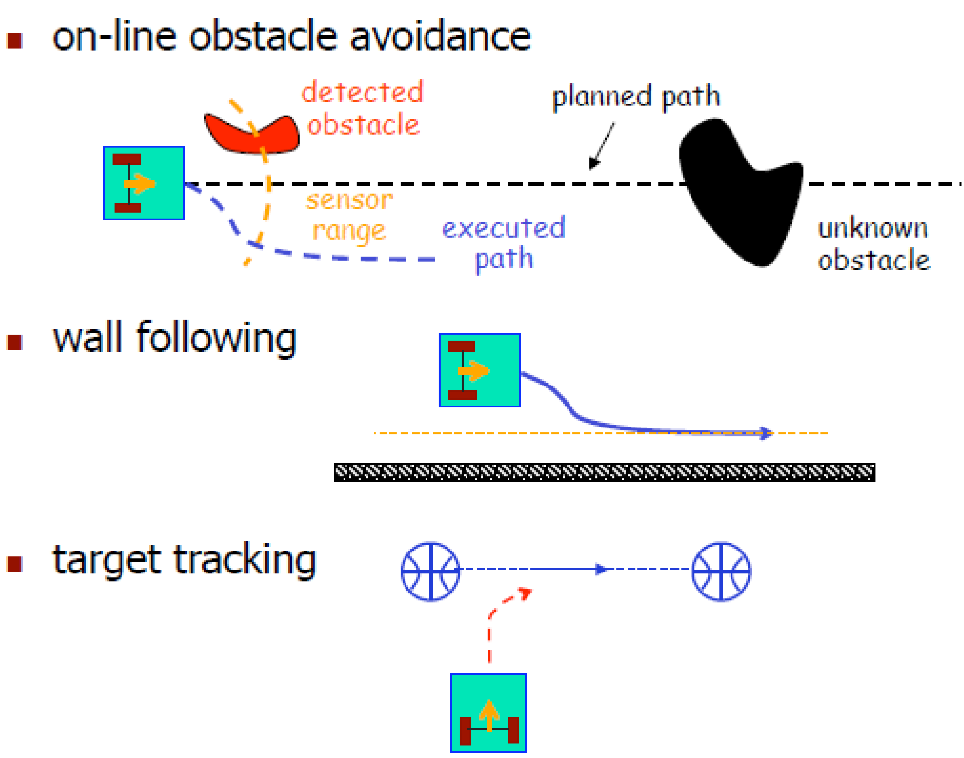

Figure 3. Examples of Reactive Motion.

3.1 Wheels of a WMR

The wheels of a WMR (Wheeled Mobile Robot) can be classified as conventional (directional) and omnidirectional [16].
Conventional wheels include

- fixed wheel (fixed axis and support)
- centered orient able wheel
- off centered orient able wheel (castor wheel)

Omni-directional wheels include

- Swedish wheel/ Mechanism
- Spherical wheel

Conventional robots have a non-holonomic constraint i.e. they can move in a certain direction (forwards and backwards), but not others (side to side). Generally, the conventional wheel only has a tangential velocity in direction of the desired direction. Omnidirectional wheel on the other hand has a normal velocity in direction perpendicular to the tangential velocity to facilitate the side by side motion of the wheel.

3.2 Modelling of the Wheeled Mobile Robots

i) Kinematics Constraints [17-22]:

We consider a mechanical system with n generalized coordinate's 'q' subject to 'm' kinematic constraints:

$$A(q)\dot{q} = 0 \tag{1}$$

where: $A \in R^{m \times n}$ is a full rank matrix [1]. Wheeled vehicle and mobile robots involve kinematics constraints like many other kinematic systems.

4 Kinematic Model

Let's consider the kinematics model [23-28] for an autonomous vehicle. The position of the mobile robot in the plane is shown below [29].

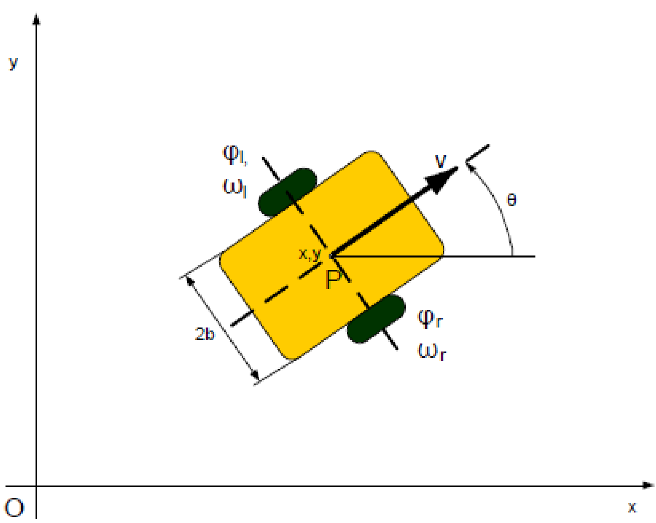

Figure 4. Position of mobile robot in a plane.

The inertial-based frame (Oxy) is fixed in the plane of motion and the moving frame is attached to the mobile robot. We will assume that the mobile robots are rigid cart equipped, with non-deformable conventional wheels, and they are moving on a non-deformable horizontal plane. During the motion: the contact between the wheel and the horizontal plane is reduced to a single point, the wheels are fixed, the plane of each wheel remains vertical, the wheel rotates about its horizontal axle and the orientation of the horizontal axle with respect to the cart can be fixed. The contact between the wheel of the mobile robots and the non-deformable horizontal plane supposes both the conditions of pure rolling and non-slipping during the motion. This means that the velocity of the contact point between each wheel and the horizontal plane is equal to zero. For low rolling velocities this is a reasonable wheel moving model. The center of the fixed wheel is a fixed point of the cart and b is the distance of the center of the wheel from P. The rotation angle of the wheel about its horizontal axle is denoted by Φ(t) and the radius of the wheel by R. Hence, the position of the wheel is characterized by two constants: b and R and its motion by a time-varying angle: $\Phi_r(t)$ – the rotation angle of the right wheel and $\Phi_l(t)$ – the rotation angle of the left wheel. The configuration of the mobile robot can be described by five generalized coordinates such as:

$$q = [\, x, y, \theta, \Phi_r, \Phi_l]^T \tag{2}$$

where:
x and y are the two coordinates of the origin P of the moving frame (the geometric center of the mobile robot),

θ is the orientation angle of the mobile robot (of the moving frame),

$\Phi_r(t)$ – the rotation angle of the right driving wheel,

$\Phi_l(t)$ – the rotation angle of the left driving wheel.

The vehicle velocity v can be found in equation (3):

$$v = R(\omega_r + \omega_l)/2 \tag{3}$$

where:

$\omega_r = \frac{d\Phi_r}{dt}$ - angular velocity of the right wheel,

$\omega_l = \frac{d\Phi_l}{dt}$ - angular velocity of the left wheel,

The position and the orientation of the mobile vehicle are determined by a set of differential equations (4-6) in the following form:

$$\dot{x} = (R\cos\theta\,(\omega_r + \omega_l))/2 \tag{4}$$

$$\dot{y} = (R\sin\theta\,(\omega_r + \omega_l))/2 \tag{5}$$

$$\dot{\theta} = R\,(\omega_r - \omega_l)/2b \tag{6}$$

Here,

$$\dot{x} = v \cos\theta \tag{7}$$

$$\dot{y} = v \sin\theta \tag{8}$$

Then the matrix form is:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \dot{\theta} \end{bmatrix} \tag{9}$$

Finally the kinematics model of the vehicle velocity v and the angular velocity $\dot{\theta}$ can be represented by the matrix as follows:

$$\begin{bmatrix} v \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} R/2 & R/2 \\ R/2b & -R/2b \end{bmatrix} \begin{bmatrix} \omega_r \\ \omega_l \end{bmatrix} \tag{10}$$

In this case, we now consider the mobile robot motion as a non-holonomic mechanical system, where three kinematics constraints exist:

$$\begin{aligned} \dot{x} \sin\theta - \dot{y} \cos\theta &= 0 \\ \dot{x} \cos\theta - \dot{y} \sin\theta &= R\omega_r - b\dot{\theta} \\ \dot{x} \cos\theta + \dot{y} \sin\theta &= R\omega_l + b\dot{\theta} \end{aligned} \tag{11}$$

The constraints can be written in the form (1), where matrix A $\in R^{m \times n}$ (m=3, n=5) can be described as:

$$A = \begin{bmatrix} \sin\theta & -\cos\theta & 0 & 0 & 0 \\ \cos\theta & \sin\theta & b & -R & 0 \\ \cos\theta & \sin\theta & -b & 0 & -R \end{bmatrix} \tag{12}$$

In this paper the angular velocities of the two wheels of the mobile robot are independently controlled. In this review, we neglect dynamic matters [30-33]: contacts [34, 35], vibrations [36-42], deflections [43-49] and accuracy [50-59] of robot realization and mounting [60-65].

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