Research Article

Posture Stabilization and Trajectory Tracking: A Kinematic Analysis of Differential Drive Wheel Robot

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Abstract- The objective is navigation of mobile robot in a real world dynamic environment avoiding structured and unstructured obstacles either they are static or dynamic. The shapes and position of obstacles are not known to robot prior to navigation. The mobile robot has sensory recognition of specific objects in the environments. This sensory-information provides local information of robots immediate surroundings to its controllers. The information is dealt intelligently by the robot to reach the global objective (the target). Navigational paths as well as time taken during navigation by the mobile robot can be expressed as an optimisation problem and thus can be analyzed and solved using various techniques are studied in literature.

Keyword Kinematic analysis study, Technique , Mechanical machine

1 Introduction

Mobile robots are intelligent agents which can perform desired tasks in various (known and unknown) environments without continuous human guidance. Many kinds of robots are working in 360 degree. One important area of robotics research is to enable the robot to cope with its environment whether this is on land, underwater, in the air, underground or in space.

A fully working in the real world has the ability to:

- Gain information about the environment.
- Travel from one point to another point, without human navigation assistance.
- Avoid situations that are harmful to people, property or itself.
- Repair itself without outside assistance.
- Learn or gain new capabilities without outside assistance.
- Adjust strategies based on the surroundings.
- Adapt to surroundings without outside assistance.

Mobile robotics is a challenging research topic for several reasons. First, a mobile robot should able to identify features, detect obstacles, patterns and target, learn from experience, find a path and build maps, and navigate. These abilities of mobile robot require the simultaneous application of many research disciplines (e.g. Engineering and computer science).

Secondly, mobile robots are the closest approximation of intelligent agents. For centuries people have been interested in building machines that can think and make decisions based on the environment around them. To satisfy this goal mobile robotics research has increasingly incorporated artificial intelligence enabling the machines to mimic living beings. Thirdly, there are many applications for mobile robots. Transportation, surveillance, inspection, cleaning and entertainment, military operations in complex hazardous environments, hostile environments such as Mars trigger even more unusual locomotion mechanisms, are just some examples. Other commercial robots operate not where humans cannot go, but rather share space with humans in human environments.

These robots are compelling not for reasons of mobility but because of their autonomy, and so their ability to maintain a sense of position and to navigate without human intervention is paramount. The design of mobile robots involves the integration of many different bodies of knowledge. To solve locomotion problems, the mobile robot must understand mechanism and kinematics, dynamics and control theory. Localization and navigation demand knowledge of computer algorithms, information theory, artificial intelligence, and probability theory. A general control scheme of autonomous mobile robot system has been illustrated in Fig.1.1. To be sure, some form of high-level control is required to ensure that the robots do not harm any humans being or equipment or other robots. In effect, this high level of control implies an implementation of Asimov's laws (1950).

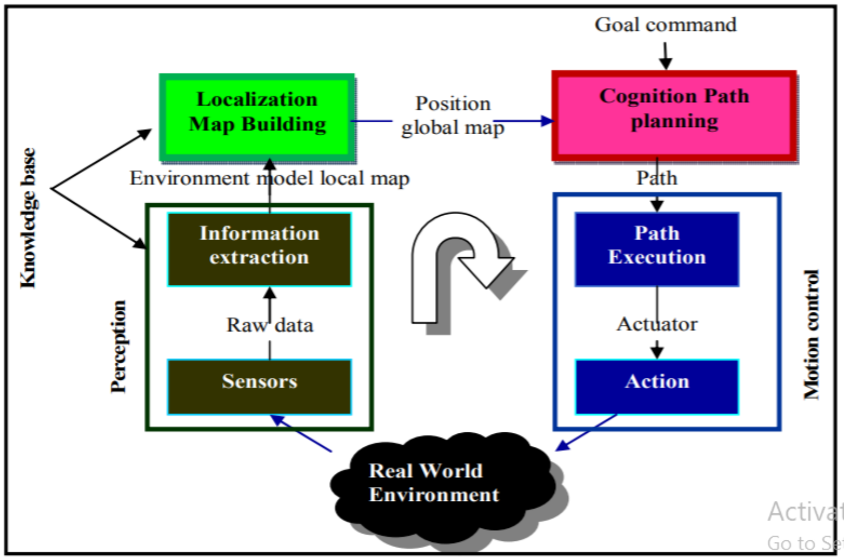

Figure 1.1.General control scheme of autonomous mobile robot system.

2. Literature Review

The development of techniques for autonomous navigation in real-world environments constitutes one of the major trends in the current research on robotics. One of the main problems in mobile robot navigation is the determination of the robot position [1]. An important problem in autonomous navigation is the need to cope with the large amount of uncertainty that is inherent of natural environments [2]. Navigation of mobile robot is an active area of research with many potential military and civilian applications. Yet, there are many unsolved problems which probably either need a breakthrough in the current theories or a completely new approach for the solution. Extraordinary abilities of humans in doing these tasks without any measurement have inspired many researchers [3]. Navigation for mobile robots can be well-defined in mathematical (geometrical) terms. It also involves many distinct sensory inputs and computational processes. Elementary decisions like turn left, or turn right, or run or stop is made on the basis of thousands of incoming signals [3-6]. Thus it is necessary to define what navigation is and what the function of a navigation system? Navigation is traditionally defined as the process of determining and maintaining a trajectory to a goal location [5]. Biological navigation behaviours have been an important source of inspiration for robotics in the past decade. According to Levitt and Lawton [7], navigation consists of answering three questions: (a) "Where am I?" (b) "Where are other places with respect to me?" and (c) "How do I get to other places from here?" However, biological systems do not necessarily require all that knowledge to navigate, but they usually work on a "how do I reach the goal?" basis. Most systems typically deal with different degrees of knowledge depending on the circumstances. Navigation can be classified as t

3Methodologies

The kinematics of mobile robot focuses on design of mobile platforms to perform intelligent tasks, rather than on the development of methodologies for analyzing, designing, and controlling the mobility subsystem. Improved mechanical designs and mobility control systems will enable the application of mobile robot to perform the task with smooth movement during navigation. Kinematic methodology is the first step towards achieving these goals. The objective is thus to model the kinematics of mobile robot. Modeling mobile robots with differential drive wheels as control systems may be addressed with a differential geometric point of view by considering only the classical hypothesis of "rolling without slipping". Such a modeling provides directly kinematic models of the robots. Kinematics is the study of the geometry of motion. In the context of mobile robot, this chapter provides to determining the motion of the robot from the geometry of the constraints imposed by the motion of the wheels. In recent years, much attention has been paid to the motion control of mobile robots [20]. However, practically they need to take into account the specific dynamics that can produce the input velocity using wheel torque provided by the mobile robot. Broadly, the mobile guidance robots can be classified into active and passive types. An active mobility assist robot can be controlled using DC motor or servo motors while the user is guided within the environment. A passive mobility assist robot need not have actuators on the wheels but only brakes or the actuators may only steer the wheels. The active robot can perform complicated motions and enhance the overall maneuverability. However, the user's safety needs to be considered in the development of such mobile assistive robots [21]..

2.1 Type of Wheels used in Mobile Robot

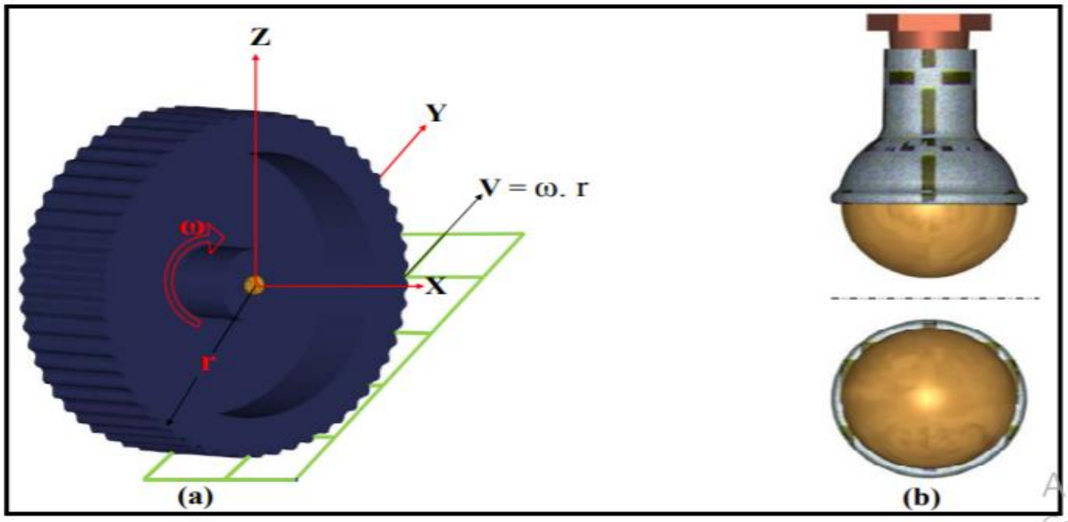

Figure 3.1.(a) Schematic view of conventional wheel and (b) Ball wheel used in mobile robots.

2.1.1 Analysis of Wheel Kinematic Constraints

The first step to a kinematic model of the robot is to express constraints on the motions of individual wheels. The first constraint enforces the concept of rolling contact that the wheel must roll when motion takes place in the appropriate direction. The second constraint enforces the concept of no lateral slippage, that the wheel must not slide orthogonal to the wheel plane. The fixed standard wheel has no vertical axis of rotation for steering. Its angle to the chassis is thus fixed, and it is limited to motion back and forth along the wheel plane and rotation around its contact point with the ground plane.

$$[\ \sin(\alpha+\beta) - \cos(\alpha+\beta)(-1)\ \cos\beta]R(\theta)xq=\omega R]\ \ldots.1$$

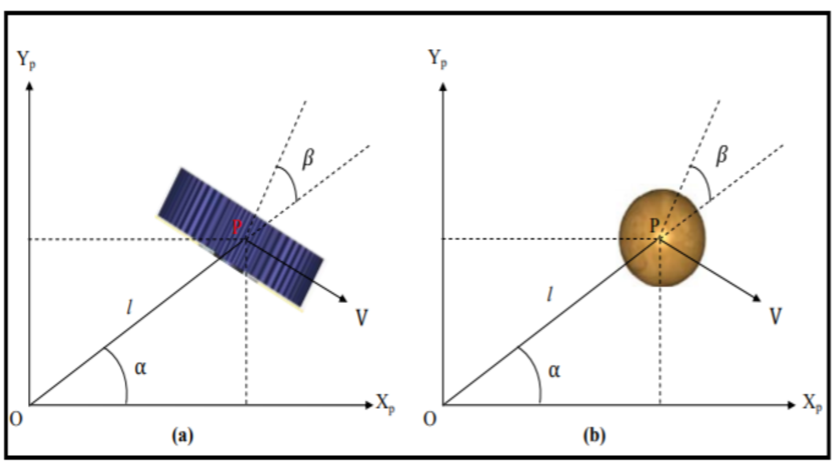

Figure 3.2. Kinematic parameters of (a) Standard wheel (b) Ball wheel.

Fig. 3.2 depicts a fixed standard wheel and indicates its position pose relative to the robot's local reference frame. The position of P is expressed in polar coordinates by distance l and angle† .The angle of the wheel plane relative to the chassis is denoted by ŧ, which is fixed since the fixed standard wheel is not steerable. The wheel, which has radius r, can spin over time, and so its rotational position around its horizontal axle is a function of time t: ω and t.

2.1.2 Motion Control

A common task in mobile robotics is to drive the robot to a certain position and orientation as fast as possible given the limits of the static and dynamic properties of the robot setup. Kinematic models and motion-control algorithms for a differential drive has been discussed in this section. A partially compliant frame provides roll and yaw degrees of freedom between the axles. Motion control of nanholonomic mobile robot can sub divided in two methods one is open loop control and another one is close loop control method which have been exhibited in next section

Kinematic Analysis of Mobile Robot The kinematics analysis of mobile robot which has been used for experimental validation is analyzed in this section. The driving wheels are independently driven by two actuators (motor 0 and motor 1) to achieve the motion and orientation. All wheels have the same diameter denoted by '2r' as shown in Fig. 3.4. The left and right driving wheels are separated by distance 'W'. The center of gravity (COG) of the mobile robot is located at point 'C'. The point 'P' is located in the intersection of a straight line passing through the middle of the vehicle and a line passing through the axis of the two center wheels. The distance between points P and C is 'd'. The kinematics of the differential drive mobile robot is based on the assumption of pure rolling and there is no slip between the wheel and surface.

Dynamic Analysis of Mobile Robot The simplified version of the dynamic model used in for differential driven mobile robot. In this simplified model, the mass and the moment of inertia of the two wheels are considered to be negligible compared to those of the robot platform. The Euler–Lagrange equations of motion are used to derive the dynamics of the mobile robot [24].

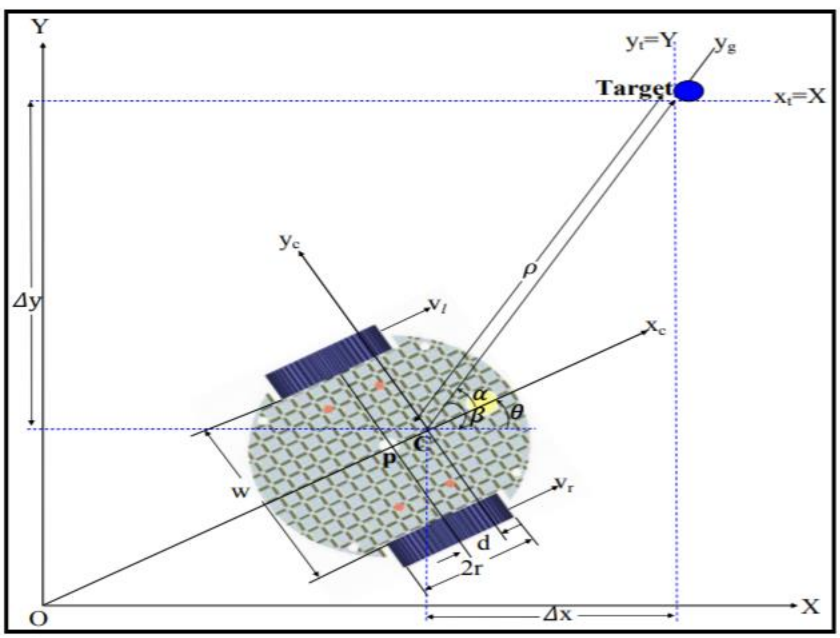

Figure 3.4. Kinematic analysis of mobile robot

$V_t = 1/2[V_r + V1]$ … 2

$\omega T = 1/w[V_r - V1]$ … 3

$Vr = r\omega_r$ and $Vl = r\omega_l$…….4

Where

V = linear velocity and

ω = angular velocity of the mobile robot.

Suffix r, *l* and t stand for right, left wheel and tangential (with respect to its center of gravity point 'C' measured in a right wheel) respectively.

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The position of the robot in the global coordinate frame (O X Y) is represented by the vector notation as,

$$q=[\ x_c y_c \theta]^T \ldots\ldots\ldots\ldots\ldots 5$$

Where,

$x_c$and $y_c$are the coordinates of the point C in the global coordinate frame (Fig.3.4).

θ is the orientation of the local coordination of the local coordinateframe (C $x_c y_c$) attached on the robot platform measured from the horizontal axis. Three generalized coordinates can describe the configuration of the robot as Eq. (5).

$$A(q)q=0 \ldots\ldots\ldots.5$$

Where,

A(q)is the input transformation matrix associated with the constraints, and,

$$C^T(q)\ A^T(q)=0 \ \ldots\ldots\ldots..6$$

Where,

C(q) is the full rank matrix formed by a set of smooth and linearly independent vector fields spanning the null space of $A^T(q)$.

From Eq. (5) and Eq. (6)

It is possible to find an auxiliary vector time function V (t) for all time't'.

$$q=C(q).V(t) \ \ldots\ldots\ldots 7$$

The constraint matrix in Eq. (5) for a mobile robot is given by

$$A(q)=(-\sin\theta\ \cos\theta\ -\ d\ ]\ldots\ldots\ldots\ldots.8$$

$$V(t)=[v\ \omega]^T\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

The control laws are designed to produce suitable left and right wheel velocities for driving the mobile robot to follow required path trajectories. The steering angle (SA) can be computed as,

$$SA = Vl-Vr/W \ \ldots\ldots\ldots\ldots..10$$

Where,

Vl&Vrare left and right wheel velocities and w is the wheel base.

If Vl>Vrthe steering angle is in clockwise direction and if Vl<Vr the steering angle is in counterclockwise direction. The control problem is to find a suitable control law so that the robot can follow desired trajectory.

3Conclusions

Stabilization of the kinematic model of a differential drive mobile robot has been developed. The proposed dynamic controller can track the desired velocity, which is generated by kinematic controller, without exact knowledge about the dynamic model of a mobile robot. With the help of developed methodology, the robot can achieve path following as well as velocity tracking, considering both kinematic model model of the mobile robot. The details of kinematics of mobile robot is addressed and solved using a discontinuous, bounded, time invariant, state feedback control law. The exact knowledge about the parameter values required to track the desired velocity, which is generated by kinematic controller. It has been seen using the above stability condition the robot exponentially converges to the goal position. Moreover, the derivation of a stabilizing controller for the dynamic model allows a direct implementation of the proposed control law on real systems.

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