Mechatronics 37 (2016) 79–88

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Optimal control at energy performance index of the mobile robots following dynamically created trajectories

Krzysztof J. Kaliński, Michał Mazur*

Gdańsk University of Technology, Poland

ARTICLE INFO

Article history:
Received 22 August 2015
Revised 12 January 2016
Accepted 14 January 2016
Available online 3 February 2016

Keywords:
Wheeled robots
Nonlinear systems
Dynamics
Motion control

ABSTRACT

In practice, the problem of motion control of the wheeled mobile robots is often neglected. Wheeled mobile robots are strongly nonlinear systems and restricted by non-holonomic constraints. Motion control of such systems is not trivial task and usage of non-optimal control signals can lead to deterioration of the overall robot system's performance. In case of autonomous application of the mobile robots all parts of its control system should work perfectly. The paper presents the theory and application of the optimal control method at the energy performance index towards motion control of the two-wheeled mobile robot during the realisation of complex, dynamically created trajectories. With the use of the proposed control method the two-wheeled mobile robot can realise effectively the desired trajectory, which is generated ad-hoc by the navigation system of the robot. Thus the proposed method can be used for motion control of autonomous or semi-autonomous wheeled mobile robots. The presented results of both computer simulations and experiments indicate that the proposed method works effectively from the point of view of the motion control of two-wheeled mobile robot. Movement of the mobile robot appeared reliable and predictable during all the tests.

1. Introduction

Nowadays mobile robots can realise their tasks in dynamic environment. In such a case it is usually required a frequent calculation of local trajectory parameters of the mobile platform. The latter would be based on the goal of the global trajectory, but also take into account actual position and orientation of the mobile robot and the presence of obstacles and the other agents. Global trajectory of the robot can only be based on known, static map. It cannot take into account dynamic changes in the robot environment, movement of other agents and eventually robot's movement errors. Omission of the above circumstances could lead to unexpected collisions. Local path planner is usually responsible for correcting eventual position and orientation errors by generating forward courses of appropriate velocities of the mobile robot. In case of wheeled robots restricted by the non-holonomic constraints it could be linear and angular velocity of the mobile robot. Realisation of those velocities commands is done by motion controller. Thus typically complicated task of following the desired path at known velocity becomes simplified by following only the desired velocity courses. Position and orientation errors may be slightly greater than in classical approach for the motion control of the path. However robots' reactions to changes in the environment could be faster. Correction of the position and orientation errors of the mobile robot is realised by local path planner, instead of motion controller.

Performance of the mobile robots strongly depends on its ability to follow accurately the given trajectory. However motion control (sometimes called *low level control*) is a problem being often neglected. In case of mobile robots bounded with non-holonomic constraints, the controlled system is strongly nonlinear. Thus, commonly used methods based mainly on the PID controllers are not effective [1,2]. Their usage may lead to sluggish reactions of the mobile robot to the velocity commands. In the other case, the overly high, non-optimal driving torques may lead to slippages at the same settings of the PID controllers. The latter are strongly unwanted, because they consequently lead to deterioration of the mobile robot's performance.

Global position and orientation of the mobile robot could be only estimated by direct measurements, but it is usually impossible to achieve sufficient resolution and time of direct measurements for typical mobile robots applications. Thus, local measurements based on indirect methods are used to achieve the desired accuracy and time resolution, but they could be sensitive to the slippages of the robots wheels. The latter could be partially caused by poor quality of motion control method.

* Corresponding author. Tel.: +48 607572519.
E-mail addresses: kkalinsk@o2.pl (K.J. Kaliński), mazur.m.r@gmail.com, micmazur@pg.gda.pl (M. Mazur).

http://dx.doi.org/10.1016/j.mechatronics.2016.01.006
0957-4158/

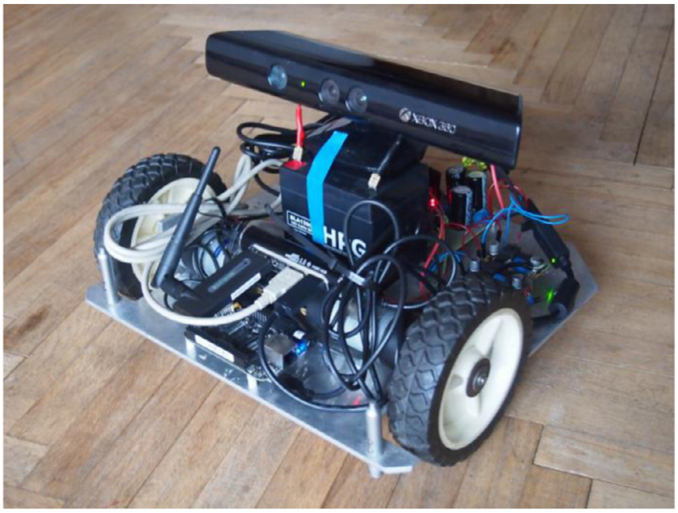

Fig. 1. Two-wheeled mobile robot.

The methods of motion control of mobile robots based on the Artificial Intelligence techniques [3,4], adaptive control methods [5,6] or robust control methods [7] allow to achieve the desired accuracy, but their implementation is generally not straightforward. In case of microscale problems, due to restrictions of computational resources, limitation of the movement errors could be achieved by introducing sophisticated movement mechanisms [8]. In this article is presented a method of motion control which is both effective and easily implemented, because it is based on the dynamic model of the mobile robot. The energy performance index [2,9] which is applied for computation of the optimal control signals has physical interpretation; it expresses an instantaneous mechanical energy of the mobile robot. Both computer simulations and experimental results show that the presented method appears to be very effective and accurate for a low level control of mobile platforms.

The proposed method of control has been already applied with success in many practical applications [1,2,9–11]. Three-wheeled mobile robots have two wheels driven through the differential mechanism, and one (usually front) wheel steered by second, independent motor. Theory of control of such robots was introduced in [12]. Hardware in the Loop Simulations (HILS) of the two-wheeled mobile robot's mechanical part with the use of Real Time operating system and the proposed method of control, was initially elaborated in [13]. Full mechatronic procedure (including HILS) for building the controlled three-wheeled mobile robot was presented in [14]. However behaviour of all the approaches is based on definition of the desired static trajectory.

2. Material and methods

Two-wheeled mobile robot (Fig. 1) was the basis of creating the dynamic model for a purpose of computer simulations and the experiments. This robot was built as a low-cost solution. As the name suggests it is equipped with two driven wheels. Kinematic scheme of this platform is presented in Fig. 2. The driven wheels (1 and 2) are situated symmetrically at the both sides of the robot and they are connected through the integrated planetary gearboxes to the DC motors (i.e. Micro Motors E192.12.25). In order to achieve static stability, the third castor wheel (3) is situated in the back of the mobile robot. Indirect measurements are performed with the use of encoders (ME22: 2 channels, 200 steps per revolution), which are connected directly to the DC motors' shafts. This type of measurement is called *indirect*. Slippages between driven wheels and the surface, which may occur during the robot movement, could lead to arise position and orientation errors. The slippages are not the only one source of the errors, which may occur during measurements by the encoders,

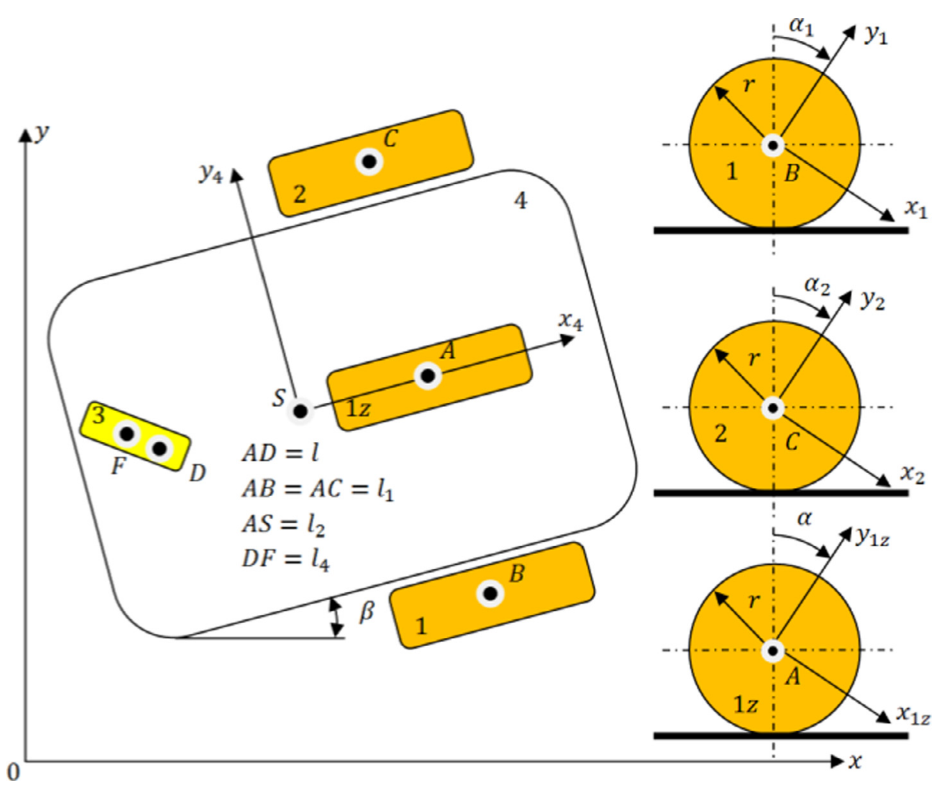

Fig. 2. Kinematic scheme of two-wheeled mobile robot.