Mobile Robot Path Planning Using Omnidirectional Wheels in Known or Partially Known Enviroments

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Abstract: *This contribution brings an evaluation of current state of the research plan "Simulative modelling of mechatronic systems" which is being carried out on the institute ÚVSSR FSI BUT in Brno within the year 2005. There is chosen the conception of locomotive mechanism of Autonomous Locomotive Robot (ALR) for indoor environments. On the basis of the morphological analysis method, and consequently the method of multicriterial assessment there was chosen an undercarriage with omnidirectional wheels. Futher, in this contribution, there are described methods for global path planning of ALR in known (or partially known) environments. The attention is also paid to the undercarriage motion modelling, taking into account the usage of omnidirectional wheels. The final part is then to determine the aims in the following year 2006 which are focused mainly on implementation of both physical model and control system of ALR.*

Keywords: *Mobile Robot, Omniwhee platforml, Path Planning, Multiprocessor Control*

I INTRODUCTION

The analysis of problems within path planning and local path control of ALR (Autonomous Locomotive Robot), as a mobile system, is consisted particularly of these essential classes:

- machineware
- hardware
- software
- brainware

There are examined two levels of planning algorithms:

- higher (high – level)
- lower (low – level)

The higher level path planning of moving ALR embodies algorithms for global path planning. These algorithms determine the selection of an acceptable path with the aim of reaching the target position. This level is independent of mobile robot architecture and there are embodied methods of searching state space.

The lower level of path planning embodies methods in connection with properties of chosen conception of mobile robot undercarriage (kinematics of locomotive mechanism - undercarriage) and is used for correction of set path. With regard to the accepted kinematical model (e.g. wheeled undercarriage), there is essential for this level to derive the mathematical relations for demanded both angular velocities and angular orientation of directional wheels. In case of proposal there is also necessary to take into account the change of position and orientation of mobile robot.

Path planning of ALR can be pursued, one the one hand, in known environments when is available the whole 2D or 3D map. On the other hand, the environment might be totally unknown when is necessary to deal with exploration of an environment and building maps (e.g. metric or topological) for the purpose of mobile robot navigation. Certain intermediate stage between these two extremes represents the partially known environments.

II THE PAPER

1 Specification of Aims and Objectives for the Project

Primary aims here were determined with respect to the research plan as follows:

- Analysis of the current state in the area of global path planning and local navigation of mobile robots in known environments.
- Proposal and carrying out of next generation of a physical model of autonomous locomotive robot (ALR).
- Proposal and carrying out of Control System (CS) of ALR by means of the newest MW, HW, SW and BW means.
- Working-out of global path planning method for ALR of higher generation.
- Conceptional proposal of local navigation algorithm for ALR using the accepted kinematical structure.
- Realization of complex navigation system and its following implementation on the real model of ALR.

2 Conception of Locomotive Mechanism of ALR

With regard to the known fact that modelling of robotic systems require exact mathematical description of kinematical structure within the chosen type of undercarriage (locomotive mechanism of mobile robot as a followed-up technical object) there was, on the basis of selection by the method of morphological analysis and consequently used method of multicriterial assessment of proposed solutions, chosen a symmetric undercarriage with omnidirectional wheels in order to simulate the behaviours, properties and characteristics of the mobile robot.

3 Kinematical Model of the ALR

The position of mobile robot is determined by the matrix:

$$P = \begin{bmatrix} x_R \\ y_R \\ fi_R \end{bmatrix} \qquad (1)$$

where

x_R, y_R is coordinate of the robot in chosen coordinate system

fi_R is orientation of the robot

Velocity of the robot is determined by the following matrix:

$$V = \begin{bmatrix} \frac{dx_R}{dt} \\ \frac{dy_R}{dt} \\ \frac{dfi_R}{dt} \end{bmatrix} \qquad (2)$$

where

dx_R/dt, dy_R/dt are components of velocity in x and y direction

dfi_R/dt is velocity of undercarriage rotation.

Angular velocities of robot's wheels are described by the next matrix:

$$O = \begin{bmatrix} o_1 \\ o_2 \\ o_3 \end{bmatrix} \tag{3}$$

where

o_1, o_2, o_3 are angular velocities of driving units.

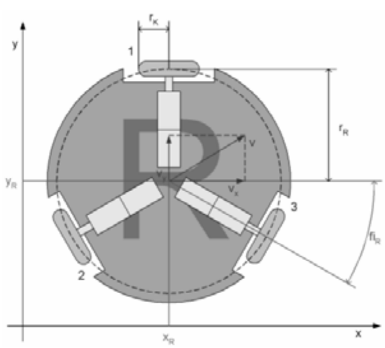

Figure 1
Kinematical structure of ALR with omnidirectional wheels

Desired values of angular velocities of wheels can be computed by the following relation:

$$O_Z = \frac{A^{-1}.C.V_Z}{r_K} \tag{4}$$

where

V_Z are desired values of robot's velocities (output from the controller of position and orientation)

r_K is radius of robot's wheel

next

$$A = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{3.r_R} & \frac{1}{3.r_R} & \frac{1}{3.r_R} \end{bmatrix} \tag{5}$$

where

r_R is radius of robot's undercarriage

and

$$C = \begin{bmatrix} \cos(fi_R) & \sin(fi_R) & 0 \\ -\sin(fi_R) & \cos(fi_R) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Actual values of robot's velocities and consequently robot's position and orientation can be computed on the basis of following relations:

$$V_S = r_K.C^{-1}.A.O_S \tag{7}$$

where

O_S are actual values of angular velocities of individual driving units

4 Simulation and Modelling of Drive of ALR in Known or Partially Known Indoor Environments

In accord with the research plan there is an assumption of using simulation tools mainyl for development and testing the proposed algorithms. In this case, simulation and modelling of drive of ALR in surrounding technological scene are devided into the two individual parts.

The first part is dealing with path planning of mobile robots in known or partially known environments whereas the second part is focused on modelling of the undercarriage using omnidirectional wheels.

5 Path Planning of ALR in Known or Partially Known Environmets

For the purpose of path planning of mobile robot there were selected two methods. The first method simulates the motion of the robot from the START point that the robot is moving in all directions simultaneously.

The second method describes the working environment by means of nodes and distances amongst them. The robot motion is then performed over these nodes.

5.1 Method Simulating of Wave Propagation

This method simulates the propagation of "vawe" from the START point. It is in accordance with approach – "if you do not know which direction to go, set out in all directions".

Working environment has to be adjusted before the method it to start. It is dealt with obstacles enlargement by a minimal distance (safety distance from objects), which is in case of circular and symetric undercarriages equaled the radius of the undercarriage.

The method then passes through the whole working environmnet cyclically and in each cycle there are checked all points of free working environmnet. If a point is located near (in environment of 3x3 pixel) an already active point (where the wave has already reached), then the point is also set as an active. The value of a point is computed as a minimum of distances from active neighbours. The method is finished when the GOAL point is set as an active. A path from START to GOAL position is searched for backward. However, the direction of a path is determinated by the highest change of active points values.

Experimental results of this method:

- Size of working environment [pixel]: 340 x 448
- Path length [m]: 33,4737
- Computation time [s]: 391,0940

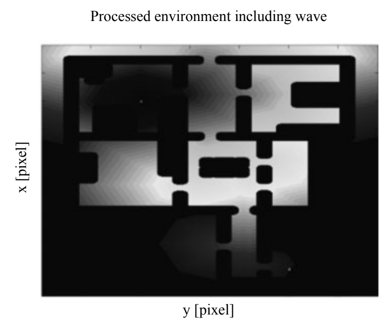

Figure 2 a)
Propagation of wave within free working environment

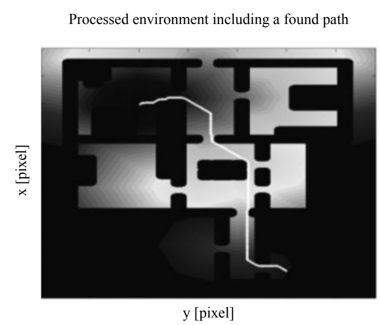

Figure 2 b)
Backward searching of a path from GOAL to START point

5.2 Method of Searching Path by Nodes and Links

The basis of this method is constituted by two separated parts:

1. Processing of environment and preparation of the list of nodes and distances amongst them.
2. Incorporating of START and GOAL points to the list of nodes.

The advantage of this method is, that by change of working environment there has to be performed only the first part of the method. After setting up START and GOAL points there has to

be, vice versa, performed only the second part of the method. Before start of the method there is necessary to preprocessed the environment; objects enlargement by a minimal (safety) distance. Method is then to check all points of free working environment. Provided that a point is a node (on the basis of set rules known in advance), the point is marked. In the next step there are searched links amongst individual nodes which do not pass through neither any obstacles nor a further node. After setting up START and GOAL points there is performed some modification of the list of nodes. After that, there are computed distances to individual nodes specially for START as well as for GOAL.
There is used the Dijsktra's algorithm with a possibility of setting the degree of heuristics while searching. On the basis of the list of points found during path planning, is then described a trajectory for motion steering of the robot.

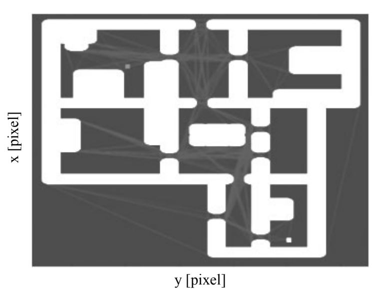

Figure 3 a)
Nodes and links amogst nodes including START and GOAL points

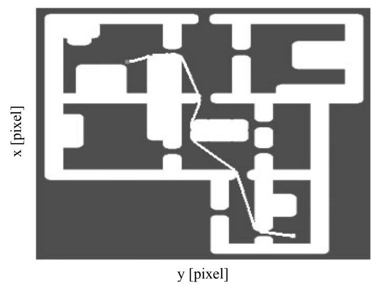

Figure 3 b)
The shortest path found from START to GOAL point

Experimental results of this method:

- Size of working environment [pixel]: 340 x 448
- Computation time of 1st part of the method [s]: 15,61
- Path length [m]: 31,9753
- Computation time of 2nd part of the method [s]: 2,594

5.3 Summary

The method of searching path by nodes and links seems to be ideal choice for path planning of mobile robots capable of turning round the same place. Demands on the control system power can be considerably decreased by suitable option of method parameters (size of one pixel and size of robot). With respect to the strong points of this method (method of searching path by nodes and links) there is counted in just with this method for the future work.
Path planning in partially known environment is carried out in the same way as in known environment. While the robot is moving, there is checked the surroundings a it is compared with the map saved in memory. Provided there is detected a bigger difference,

the map is updated and the path is recalculated.

6 Modelling of Mobile Undercarriage with Omnidirectional Wheels

In order to create a virtual model of robotic system (OMNIROBOT), there was used software MathWorks Matlab 7 and its simulative toolkit Simulink. The system is consisted of two main parts:

1 Mobile undercarriage with control system of driving units.
2 Controller of robot's position and orientation.

Using this model there was verified functionality of the controller of position and orientation using mobile robot undercarriage with three omnidirectional wheels. Signalization of reaching the desired position and orientation can then be utilized in real system as a demand for setting subsequent desired values. The correctness of mathematical description of undercarriage's kinematics can be examined by time behaviours.

7 Proposal of Multiprocessor Control System of ALR with Omnidirectional Wheels

The control system will be consisted of three main, mutually relating parts:

1 Mobile undercarriage with multiprocessor control system; control system of the mobile robot will be divided into several function blocks. Each block will perform specific function, where the division is based on the structure of navigational and application method.
2 The modul of higher layer of control which represents input/output communication gate and can be used for specification of activities of ALR, inserting global map and monitoring these activities.
3 Mobile control systems using for monitoring and potentially for controlling activities of ALR.

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