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Analysis of Existing Infliences in Formation of Mobile Robots Trajectory

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Abstract: *The work considers and analyzes three main ways of forming trajectory of movement: coordinate trajectory and vector. The choice of description method depends on conditions of specific problem. The specificity of different type's movement of robots is analyzed: wheeled, tracked and walking. One of features in formation of movement trajectory in space with dynamic obstacles is speed. Thus, analysis of impacts is especially important for those robots that are able to achieve significant speeds and accelerations, as well as for robots characterized by large load capacity, while dynamic effects are associated with significant masses in structural elements. Today, there is no unified universal approach to constructing trajectories in environment with obstacles. The analysis showed that formation of rational trajectory taking into account: length and smoothness of trajectory; nature of workspace and map of area; safety – distance to obstacles; type of mobile platform (method of moving robot) will ensure correctness and conflict-free trajectory.*

Keywords—analysis; factors; influence; trajectory; robot.

1. Introduction

Modern mobile robots (MR) have ability to solve many different tasks, including independently planning trajectory of movement, bypassing obstacles on way [1]-[5].

The movement of robots can be considered in different aspects: way of movement, kinematic diagram and structure of robot, or choice of method for designing trajectories of mobile robots movements, etc. This topic is extremely broad.

In this work, we will focus on analysis of existing influences in formation of MR movement trajectory.

The MR movement methods include: walking, robots on wheeled or tracked platforms, flying, etc. [5]–[8].

The variety of ways to move mobile robots is wide enough that it becomes prerequisite for fact that MR can navigate most difficult landscapes, dangerous places for humans, rugged terrain, glide in air or conquer elements of sea.

To achieve this goal, MR needs not only to execute commands, but also to move along certain trajectory, for preliminary formation of which information is needed about environment / space in which movement will be performed.

For effective functioning, intelligent robots are equipped with system for sensing environment, means of analyzing situations and making decisions, and planning movement (including building route).

The problems related to study of mobile robots movement dynamics and calculations of their control are relevant due to fact that there are higher requirements for functioning accuracy of such systems, conditions for formation of control schemes that provide features of smooth dynamic movements, it becomes necessary to take into account effect of what is compliance of wheels and other characteristics of movement of robots. It is also necessary to use various methods, approaches, algorithms [9]-[14].

There is certain class of new approaches that allow solving corresponding problems. Gaps are eliminated and appropriate work management scheme is built.

At the moment, one of central problems in control and planning of robots movement is formation of trajectories.

2. Related Work

Today, a lot of attention is paid to formation of robots movements trajectories.

There is variety of algorithms and methods for constructing trajectories for robots: mobile and manipulators [15]-[19].

Some features of route planning as basis of mobile robot were previously considered by us in [4]. We considered main tasks of planningroute of mobile robot, among which were highlighted: building map of robot's motion environment and adjusting trajectory of robot. The article discusses the main points of such generalization, and provides algorithms for solving specific problems.

The algorithm for optimal planning of mobile robots movement based on Risk-DTRRT (Risk-based Dual-Tree Rapidly exploring Random Tree) is presented in [15]. A dual-tree framework consisting of an RRT tree and rewired tree is proposed for trajectory searching. The RRT tree is time-based tree, considering future trajectory predictions of pedestrians, and this tree is utilized to generate heuristic trajectory.

In [16], an elastic band-based fast random tree learning (EB-RRT) algorithm is proposed to achieve optimal real-time motion planning for mobile robot in dynamic environment. The authors propose hierarchical structure with two planners. The global scheduler uses time-based RRT algorithm to generate valid heuristic trajectory for specific task in dynamic environment. In dynamic replanner, temporary nodes of heuristic trajectory are updated by internal compressive force and repulsion force from obstacles.

In [17] present research focuses on development of optimized path planning algorithm for robot using hybrid method after combining particle swarm optimization (PSO) algorithm with potential field method for static obstacles and potential field method (PFM) prediction for dynamic obstacles. While implementing, PSO-based potential field method, total potential, that is sum of repulsive and attractive potentials, is considered as function which is optimized using PSO algorithm.

Hybrid path planning based on safe algorithm and adaptive window approach for mobile robot in large-scale dynamic environment is presented in [18].

In [19] presents an efficient double-layer ant colony optimization algorithm, called DL-ACO, for autonomous robot navigation. This DL-ACO consists of two ant colony algorithms that run independently and successively. For easier tracking of movement of mobile robot, authors proposed piecewise B-spline trajectory smoother.

Since mobile robots can be classified as wheeled, tracked, walking and flying, formation of trajectory in all these variants will be special.

Trajectory tracking and collision avoidance for formation of two-wheeled mobile robots is described in [20].

Positioning and trajectory tracking for Caterpillar Vehicles (CVs) in unknown environments is proposes in [21]. CV positioning can be obtained using simultaneous localization and mapping (SLAM) method. The authors have developed an SLAM algorithm for CV positioning based on Lidar laser sensor. The main advantage of this method is that you don't need to use more landmarks.

The generation of walking robot trajectories and achieving a stable gait of robot are considered in [22].

3. Analysis of Ways to Form Trajectory of Movement

Trajectory planning can be viewed from perspective of planning level itself:

1. Strategic.
2. Tactical.
3. Detailed.

Strategic planning is designed to build an enlarged scheme (concept) of future trajectory, which will be refined at tactical planning stage using actual information received from autonomous orientation system.

A distinctive feature of strategic planning is use of less detailed terrain map than in tactical planning.

The detail of tactical map presentation is determined by tasks being solved, as well as by capabilities of navigation system, dimensions of robot, etc.

Detailed planning allows constructed trajectory to be supplemented and "adjusted", taking into account peculiarities of transport mechanism implementation of mobile robot, which include, for example, smallest turning radius, minimum and maximum values of acceleration and speed of movement, etc.

In autonomous robots control, one of critical tasks is procedure for planning trajectory of movement, which consists in writing off generated trajectories with finite amount of information. In control systems that assume presence of an operator in control loop (pilot, driver, etc.), this problem is absent. The operator himself generates trajectory and himself controls its development. However, if functions of planning and development are structurally separated, then description of trajectory must be somehow coordinated with lower regulatory level.

The use of large arrays approximating trajectory by points is possible solution for automatically describing generated trajectory. However, significant disadvantage of this approach is redundancy.

The specificity of robots use involves solution of following tasks in formation of requirements for steady-state modes:

- positional control task – stabilization at given point in space of base coordinates and, if necessary, with desired values of orientation angles;

- trajectory control problem – movement along base coordinates of trajectories given in space with constant speed V and given orientation of associated coordinate system axes;

- positional-trajectory control problem – moving to given point in space of base coordinates along given trajectory, with given orientation to without additional requirements for speed.

Let us consider and analyze three main ways of forming trajectory of movement: coordinate, trajectory and vector.

The choice of description method depends on conditions of specific problem.

First, let's analyze coordinate method.

Mobile work has received significant development, capable of responding to commands, identifying location of three-dimensional objects, while overcoming obstacles and moving along certain trajectory.

The main reason for creation and study of such robots is their practical significance and value as objects that can replace human labor in life-threatening production, perform work inaccessible to humans and perform monotonous and monotonous actions in an autonomous mode.

Examples of such robots are work that explored surface of different planets and satellites, work that helps people in everyday life. They also found their application in industrial practice. Routes in warehouses and factory premises are made without an operator, using guide lines located on floor, or along freely defined route within given room.

From point of view of kinematics in coordinate method, position of material point A on plane at an arbitrary time moment t is determined by two coordinates, which are projections of body on Ox and Oy axes, respectively (fig. 1).

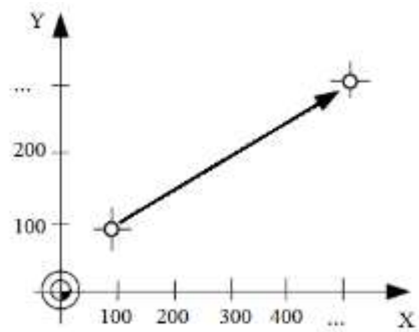

Figure 1. Coordinate way

As body moves, its coordinates change over time. If these functions are known, they determine position of body on plane at any time. In turn, velocity vector can be projected on coordinate axis and thus determine rate of change in coordinates of body [23].

By designing acceleration vector, acceleration of body along directions of coordinate axes is determined. Thus, knowing these dependencies, one can find not only position of body, but also projections of its velocity and acceleration, and, consequently, modulus and direction of vectors at any moment of time [24].

That is, with coordinate method of specifying movement of point in selected coordinate system, coordinates of moving point are set as function of time [25]. Besides Cartesian coordinate systems, other coordinate systems (spherical, cylindrical) can be used.

Then we will consider trajectory method (natural) – description of movement along trajectory. This method is used when trajectory of point is known in advance.

On a given trajectory, origin is chosen – fixed point O, and position of material point is determined using so-called arc coordinate, which is distance along trajectory from selected origin O to point A [25].

In this case, positive direction of coordinate reference is chosen arbitrarily for reasons of convenience (fig. 2).

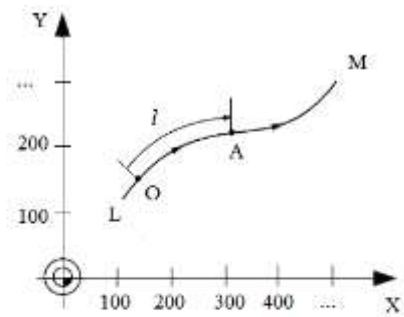

Figure 2. Trajectory method of trajectory formation

The displacement of body is determined if its trajectory, origin of reference O, positive direction of reference of arc coordinate and dependence on time are known [26].

The next two important mechanical concepts are distance traveled and average speed. By definition, path is length of trajectory segment L passing body for certain period of time [26].

That is, distance traveled is scalar and inalienable quantity, therefore it cannot be compared with displacement, which is vector. Only path and displacement module can be compared, and this path will be greater than displacement vector. The average speed of body movement is ratio of path to time interval during which this path has been traversed [26]-[28].

Traversing vector is another way to implement traversing.

The plane of movement is no longer divided into cells, as in coordinate method, and gives much more freedom for movement.

Coordinates can be specified with greater precision (not only integers, but also float values), which allows for fairly realistic movement.

The vector is direction in which object will move. In some cases, vector only indicates direction, and speed is given by additional variable.

Then it is impossible to add vector to coordinates, and vector itself must be normalized, that is, with length equal to one [25], [29].

When using vector method, position of material point A is set using so-called radius vector r, which is vector drawn from point O, corresponding to origin of selected coordinate system, to destination point A (fig. 3).

In process of material point movement, its radius vector can change both in absolute value and in direction, being a function of time.

The locus of radius vector ends r(t) is called trajectory of point A. In this case, trajectory of motion is traces (explicit or imaginary) that point A "leaves behind" after passing through one or another region of space. It is clear that geometric shape of trajectory depends on choice of reference frame, along which motion of point is observed [25], [29].

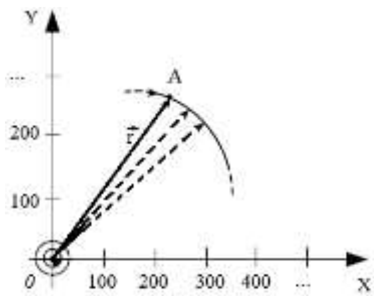

Figure 3. Vector way

Vector Ar, connects initial and final displacement of body – body displacement.

The Ar/At ratio is average velocity (average velocity vector) of body during time At.

To accurately describe movement, reverse speed is introduced, that is, speed at specific point in time t or at specific frequency of trajectory. For this purpose, time span AT is directed to use. Together with him, Ar will strive for circulation and movement.

Consequently, instantaneous velocity vector is directed tangentially to trajectory at given point in direction of body motion [25], [29].

The movement of body is usually also characterized by acceleration, which is used to judge change in speed in process of movement. It is determined by increase in velocity vector of body to time interval during which this increase occurred. With decrease in this time, orientation of vector will approach certain direction, taken in direction of acceleration vector a. Note that acceleration is directed towards a small increase in speed, and not towards the speed itself.

Thus, knowing vector, it is possible to detect speed and acceleration of body at each moment of time.

The vector method has such advantages as:

- compactness of record of kinematic relations and their independence from choice of coordinate system;

- smoother, more natural movements;

- ability to implement physics (friction, acceleration, rotation).

But some disadvantages can be identified:

- high resource consumption (calculation of root in normalization, etc.);

- complex functions that require good understanding of basics of implementing physics of an object and difficulty in obtaining information about surrounding world (you need to calculate collisions with all potential objects).

This method is quite widely used, especially where it is necessary to more accurately and perfectly convey trajectory of movement.

Ensuring purposeful movement of robot alone given trajectory with certain orientation and speed is main goal of robot control.

4. Analysis of Influence of Mobile Platform Type in Mobile Robot Trajectory Formation

When solving problem of mobile robot forming trajectory, it is traditionally considered that robot can turn in right direction around its own axis in place (tank turn).

The time it takes for robot to turn is usually irrelevant, or if fastest way is to be found, this time is neglected or so-called penalty is imposed. The very formulation of classical problem of moving robot to desired point on map is usually formulated as follows: this map with obstacles indicated on it, current state of robot and final position where you need to go.

Depending on specific task, movements are considered as:

- movement along straight line passing through stationary 2 points with constant speed V;

- rotation at given angle while moving at given speed;

- exit to stationary point with zero speed.

In process of MR moving in complex environment, it is affected by negative factors that affect ability to achieve goal. In this regard, problem arises of choosing trajectory of movement while minimizing undesirable effects on robot and length of path traveled, therefore, it is important to analyze degree of impacts.

Each MR has its own characteristics that must be taken into account. For example, some MRs are capable of reaching significant speeds and accelerations. At very high speeds and accelerations, trajectory accuracy values may be unsatisfactory. Also, implementation of programming robots without taking into account what their dynamics can cause appearance of cross-link effects, while movement of objects does not correspond to what law is given, since there is mutual dynamic effect in links of manipulators.

There have been attempts to create combined robots that could combine certain advantages walking and wheeled robots in one design. Basically, these walking robots have wheels at ends of their legs. Such structures can also function as walking mechanisms or as wheeled mechanisms, this is determined by type of surface under the robot. Due to fact that kinematic scheme inherent in most robots is non-linear, for maximum

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values of speeds and accelerations, you can note difference at different points in workspace.

That is, problem that is encountered is that MR characteristics with accuracy necessary for carrying out calculations are not defined, and some of characteristics used to solve problems of dynamics are generally unknown.

The general structure of equations of moving objects (MR) in two-dimensional space consists of movement dynamics equations, kinematics equations and drives equations.

The type of kinematic scheme of mobile robot chassis determines its maneuverability and, in many respects, controllability, introducing certain peculiarity both into procedure for forming robot's movement trajectory and into procedure for synthesizing control algorithms.

For example, model of wheeled robot movement is usually built on basis of absolutely rigid body model or system of absolutely rigid bodies connected to each other by hinges. In this case, one solid body is platform, and rest is wheels attached to it (fig. 4). Thus, position of platform is determined relative to some base coordinate system, and position of wheels is determined by rotation angle of axis associated with platform.

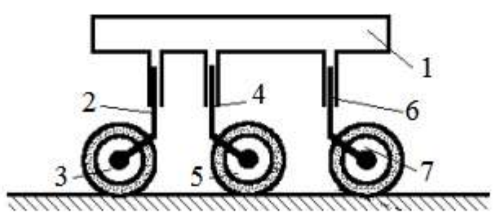

Figure 4. Mobile robot platform

In fig. 4 elements: 1 – platform; 2, 4, 6 – rotary axles of forks, 3, 5, 7 – wheels.

Consider the features of tracked robots.

The speed of autonomous robots movement, especially over rough terrain, is significantly lower and this is due to operation of autonomous control system.

One of features in formation of movement trajectory in space with dynamic obstacles is speed, and in tracked chassis, one of speed components is known to be such property as agility, which characterizes controllability of vehicle in given conditions. The behavior of mobile robot when turning depends not only on specific power, but also on dimensions of bearing surfaces of tracks; ground pressure; turning radii provided by turning mechanisms; grip properties, as well as road conditions (turning radius, coefficients of resistance to movement and turning).

In addition, speed in turn is influenced by such factors as mismatch between turning radii of roads and provided turning mechanisms, need to turn at given angle, uncertainty of movement trajectory when turning control is partially moved, ratio between external overall dimensions and width of carriageway, etc.

With controlled movement, center of mass of tracked vehicle will move tangentially to movement trajectory, and longitudinal axis will rotate around center of mass by additional angle relative to tangent to movement trajectory.

A tracked mobile robot can move in any direction on plane, subject to constraints imposed by motion equations.

Unlike a tracked robot, wheeled one has limited capabilities in choosing direction of movement, which is important to take into account when forming movement trajectory (fig. 5).

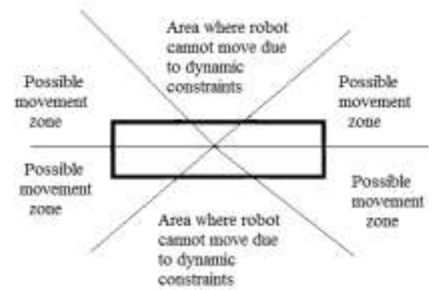

Figure 5. Possible directions of wheeled robot movement

If we compare caterpillar, wheeled and walking robot, then latter has a lot of advantages:

By movement of bipedal walking robots with balance, we mean movement of robot without falling. The movement of robot is usually set by three points of body, in total in six directions, which uniquely determines its spatial position. The connection of stop points trajectories with movement of body allows you to plan movement of feet when the robot moves in any direction, turns and changes height of supporting surface.

Thus, robot movement system (platform type) affects:

- speed or acceleration of movement;

- positioning accuracy (repeatability);

- reliability – flexibility and robustness under various conditions;

- efficiency – low power consumption.

5. Analysis of Workspace Nature Influence

An urgent problem in planning movement of MR is formation of curvilinear trajectory, while there are analytical and numerical methods for calculating optimal path of movement.

Today, there is large number of methods for forming trajectories; each of them involves solving problem in plane. This significantly reduces functionality of mobile robots moving in space (underwater, aircraft).

The possibility of spatial movement allows robots in some cases to bypass obstacles from above, without changing direction of movement in horizontal plane.

When moving in vertical plane, direction of sensitivity zone rays of robot onboard sensors is constantly changing, which can distort idea of obstacles location and lead to generation of incorrect trajectories when traditional methods are used.

In course of calculating trajectories of movement, analysis of object shape will make it possible to determine spatial location of object relative to robot's manipulator to form movement trajectories, taking into account provision of safe movement links of manipulator to avoid unwanted contacts with object.

Methods of simultaneous localization and mapping are widely used for autonomous navigation and building map of surrounding space.

In course of analysis, it was determined that key criteria in formation of robot movement trajectory with collision avoidance are:

- trajectory length;

- smoothness of trajectory;

- complexity of environment;

- complexity of environment;

- complexity of terrain map;

- naturalness of movement;

- safety – distance to obstacles.

The path length is total distance traveled by robot from start point to target. Mathematically, this criterion is to find distance between two points, which is calculated using formula. The shorter path, less time it takes robot to move from start point to end point.

The smoothness of trajectory can be determined as average value of rotation angles that robot needs to make when moving from start point to end point. Mathematically, this criterion consists in determining angle between two lines. A smaller average angle means that trajectory is fairly smooth so that robot can move from start point to end point without making too many turns, especially tight turns.

The complexity of environment is caused by high level of uncertainty in information about characteristics of environment and its constant changes, for example, moving over rough terrain with ability to solve the problem of avoiding obstacles.

Mobile robots can move in various environments: in water, air, on ground, in space. And movement in each medium has its own characteristics associated with their different physical properties.

An organized workspace is space in which control system knows coordinates of all elements of environment. Otherwise, workspace is called unorganized.

The complexity of terrain map is due to fact that part of path contains "obstacles" and is calculated taking into account need for robot to change its configuration in order to overcome obstacles as efficiently as possible.

Finding path in previously unknown environment is much more difficult to formalize, since there is no pre-compiled map (formal description of environment).

Usually, modern robots have navigation system that determines their own coordinates of robot, plans trajectory at current time and controls its movement. Since real environment in which robot is located usually contains movable / dynamic obstacles (people, other mobile robots), movement in it along predetermined trajectory is almost impossible. Taking into account parameters of dynamic obstacles allows:

- avoid collisions with obstacles;

- optimize trajectory of robot.

Considering solution of problem in static environment – simpler one, it is based on effective path method –straight line segment connecting current position of robot with current reference point.

The naturalness of MR movement is determined by smooth movements, interconnected without unnecessary pauses and movements.

Trajectory safety assessment consists in calculating shortest distance from robot to obstacles, as well as to other robots.

6. Conclusion

The work considers and analyzes three main ways of forming trajectory of movement: coordinate, trajectory and vector. The choice of description method depends on conditions of specific problem.

The movement specificity of different types of robots is analyzed: wheeled, tracked and walking. One of features in formation of movement trajectory in space with dynamic obstacles is speed.

Thus, analysis of impacts is especially important for those robots that are able to achieve significant speeds and accelerations, as well as for robots characterized by large load capacity, while dynamic effects are associated with significant masses in structural elements.

The choice of optimal movement method depends on specific conditions in which robot will work, and most often such decision is not always obvious.

So, it is necessary to form movement trajectories of mobile robots taking into account their kinematic and dynamic properties on basis of data continuously received from their on-board sensors and video cameras.

Today, there is no unified universal approach to constructing trajectories in an environment with obstacles.

The analysis showed that formation of rational trajectory taking into account: length and smoothness of trajectory; nature of workspace and map of area; safety – distance to obstacles; type of mobile platform (method of moving robot) will ensure correctness and conflict-free trajectory.

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