

## SYSTEM CONTROL'S MECHANICS OF A RELIABLE MOBILE ROBOT OPERATION WITH REGARDS TO OBSTACLES

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**Purpose:** The paper is devoted to the development of an algorithm for automatic path planning of a mobile robot (MR) to a given target point, taking into account the occurrence of obstacles on its way. The advantages of using MR in manufacturing, such as increased productivity, reduced costs, improved safety and flexibility, are discussed. State-of-the-art path planning methods including graph search, random sampling and intelligent bionic algorithms are discussed.

**Design/methodology/approach:** Special attention is given to the problem of planning safe paths in the presence of information scarcity and obstacles. The results of MP path planning modelling are presented, confirming the effectiveness of the proposed solutions. Laser range finders have been proposed to improve the safety of MR traffic. The main criteria for selecting a laser rangefinder - distance, weight, reliability, cost - are defined.

**Findings:** Path planning for MR and collision avoidance remains a topical issue and requires further research, especially in the context of integrating MR with other automated process systems and improving their reliability and safety.

**Research limitations/implications:** The research focused on modern technological processes that require a high degree of automation to increase efficiency, reduce costs and improve product quality. One of the key areas of development was the use of mobile robots (MRs) capable of performing a wide range of tasks, from transporting materials to performing complex manufacturing operations. This article deals with research on route planning for MRs, taking into account the presence of obstacles, such as people in the path.

**Practical implications:** For obstacle detection the VL53L1X laser rangefinder based on the principle of time-of-flight (ToF) measurement from the ST FlightSense product family with the parameters; distance measurement range up to 4 m, measurement frequency up to 50 Hz, independence from the obstacle color and surface reflection properties was selected. It is recommended to install 3 laser rangefinders to realize the collision detection and automatic evasion system.

**Social implications:** For reliable operation in a social environment, 3 laser rangefinders were chosen to implement the collision detection system and automatic evasive maneuver.

**Originality/value:** An original mechanics of control system for reliable operation of a mobile robot with regard to obstacles is proposed.

**Keywords.** Path planning, automation, mobile robot, obstacles, modelling.

**Category of the paper:** Case study.

## 1. Introduction

Modern technological processes require a high degree of automation to increase efficiency, reduce costs and improve product quality. One of the key areas of automation development is the use of mobile robots (MRs) capable of performing a wide range of tasks, from transporting materials to performing complex manufacturing operations. This paper considers path planning for MRs, taking into account the occurrence of obstacles such as people in the path.

The advantages of using MRs in manufacturing processes are:

1. Increased productivity. MRs can work around the clock without interruption, which significantly increases the productivity of the enterprise. They are also able to perform tasks faster and more accurately than humans, especially in monotonous and repetitive operations.
2. Cost reduction. The use of MRs reduces labour costs as they replace human labour. In addition, MRs require less maintenance and repair costs compared to traditional production lines.
3. Improved safety. MRs can perform dangerous and complex operations, reducing the risk of injury to workers. This is especially important in industries that require handling heavy loads or hazardous materials.
4. Flexibility and adaptability. Modern MRs are highly flexible and can easily adapt to changes in the production environment. They can be reprogrammed to perform new tasks, making them versatile tools for a variety of industries.
5. Integration with other systems. MRs can be integrated with other automated systems such as Manufacturing Execution Systems (MES) to create fully automated production lines.

The aim of the work is to develop an algorithm for automatic planning of the MR path to a given target point with constant scanning of obstacles on the path and taking measures when obstacles are detected (stopping the MR, giving sound and light signals or avoiding the obstacle).

## 2. Literature review on the topic of mobile robots path planning for unexpected obstacles

A good review of path planning methods for MR navigation in a dense environment is presented in Mammadova, Alieva (2022, pp. 156-165.), where MR path planning methods, their advantages and disadvantages are discussed. In Rego, Voronov (2023, pp. 264-274) the problem of MP navigation with limited information about the environment is solved. An algorithm for finding a path to the target with a minimum number of turns is described. The idea of the algorithm is based on the bug family of reactive navigation algorithms. MR memorises obstacle boundaries and calculates the turn angle depending on the environment. The difference from bug algorithms is that the robot does not move "along the obstacle", but turns only in a limited number of cases. The results of testing the algorithm on simulated polygons are presented. The efficiency is evaluated by comparing the minimum possible number of turns with the number of turns in the trajectory obtained with the algorithm.

The review article (Gazieva, 2024, pp. 73-76) is devoted to path planning methods for MR in an obstacle-ridden environment. The paper discusses various approaches to solving this problem, ranging from classical methods such as graph-based methods, cellular networks and potential field methods to modern intelligent algorithms, which are of most interest for real-world applications. The paper also discusses the applicability of these methods in different types of environments. In Yuditsev (2019, pp. 163-186), control problems in planning safe trajectories of a group of MRs are solved.

In recent years, MRs have been widely used in automated warehouses (Wen, 2022, pp. 1095-1105). When a MR operates in a warehouse, it must first accurately perceive the environment and then construct a map to navigate through. A global dynamic path planning method, which includes an improved A\* algorithm, is developed to solve the MP path planning problem. Firstly, the distance information between nodes is integrated into a heuristic function with exponential decay function as coefficients to accelerate the global optimisation search speed and improve the efficiency of path planning; secondly, the planned path is smoothed and optimised by combining the gradient descent method; finally, the A\* algorithm can perform global dynamic path planning.

In Farhud (2021, pp. 99-114), a deep learning artificial neural network is used for collision-free path planning. In Bizhanova, Salykova, Moldamurat, Ivanova (2023, pp. 339-346) methods for planning and controlling the motion of a mobile robot in an uncertain environment with stationary and moving obstacles, including random changes in the velocity vectors of moving obstacles, are considered. The methods of MP motion planning under uncertainty are analysed. The authors propose a solution in which the operation of MR using simulation modelling under uncertainty will be successful. In Barashkov (2020, pp. 51-58) the developed algorithm combining the merits of the beetle algorithm and potential fields methodology is proposed.

In Krenicky et al. (2022) the problem of MR path planning between two given points with static obstacles is solved using an integrated approach based on graph theory methods, including Voronoi diagram, visibility graph and Dijkstra's algorithm. Optimisation of the MP path length was implemented and the computational complexity of visibility graph construction was significantly reduced.

In Koshman, Bykov, Leonard, Shurygin (2024, pp. 65-71) research was carried out on MP motion planning with displacement of the potential field centre of a static obstacle, which makes it possible to exclude the possibility of oscillations of the MP centre of mass. In Sága, Bednár, Vasko (2011, pp. 269-274), an algorithm for scheduling operations in a group of autonomous MRs to eliminate the consequences of fires or emergencies was proposed.

In Pavlov (2021, pp. 38-59) algorithms for MP trajectory planning with lower computational complexity are investigated. In Li, Liu, Wang, Zhang (2021, pp. 7-10) the topical issues in the field of building an intelligent system for MP trajectory planning by means of a neural network are considered. In He, Fan, Mu, Wang (2024, pp. 63-70) a solution to the problem of insufficient performance and accuracy of real-time MP trajectory tracking is proposed by implementing a system combining machine vision and laser radar. In Mikheev, Svyatov, Lapshov (2020, pp. 70-79) a software system for determining the probability of collision of MRs with obstacles is proposed.

The analysis of the above sources shows that the topic of MR path planning and obstacle collision avoidance is very relevant and requires further research.

### **3. Development of a mobile robot path planning model**

Several key aspects have been taken into account while creating the MP path planning model in MATLAB software product:

1. Kinematic and dynamic models of the robot: a description of the robot's motion considering its kinematics and dynamics.
2. Motion control algorithms: an algorithm for path planning and motor control of the robot.
3. Feedback and error correction: processing sensor data and correcting the path if necessary.

The MR has two drive wheels and two passive support rollers at the front and rear of the platform (differential drive). Its motion can be described by the following equations:

$$\frac{dx}{dt} = V \cos(\theta)$$

$$\frac{dy}{dt} = V \sin(\theta)$$

$$\frac{dx}{dt} = V \cos(\theta)$$

where  $x$ ,  $y$  are the coordinates of MR on the plane,  $\theta$  is the angle of orientation of MR relative to the  $x$ -axis,  $v$  is the linear velocity of MP,  $\omega$  is the angular velocity relative to the centre of rotation of MR.

Laser range finders or lidars are one of the most common types of sensors used for obstacle detection and evasion. Lidars provide highly accurate measurements and are capable of operating in a variety of lighting and weather conditions. The use of lidars in MR significantly improves driving safety. The main criteria when choosing a laser rangefinder are distance, weight, reliability, and cost.

In works Jianing, Wei, Wei et al. (2021, pp. 1484-1491), Kuric et al. (2021), D'Arco, Fratelli, Graber et al. (2024, pp. 49-56), Majko et al. (2022), Qazizada, Pivarciová (2018, pp. 141-152), Nikitin, Yu (2024, pp. 137-149) a solution for obstacle detection, evasion, the problem of insufficient performance and accuracy of MR trajectory tracking in real time by implementing systems on laser radar or lidar has been proposed.

The VL53L1X laser rangefinder is selected for obstacle detection. The VL53L1X is a modern laser sensor based on the time-of-flight (ToF) principle from the ST FlightSense product family. It is a fast, miniaturised ToF sensor with a range of up to 4 m and a measurement frequency of up to 50 Hz. Unlike conventional IR sensors, the VL53L1X uses ST's latest-generation ToF technology, which allows absolute distance measurement independent of obstacle colour and surface reflectance.

The distance measurement module based on the VL53L1X laser rangefinder is shown in Fig. 1.



**Figure 1.** Laser rangefinder VL53L1X.

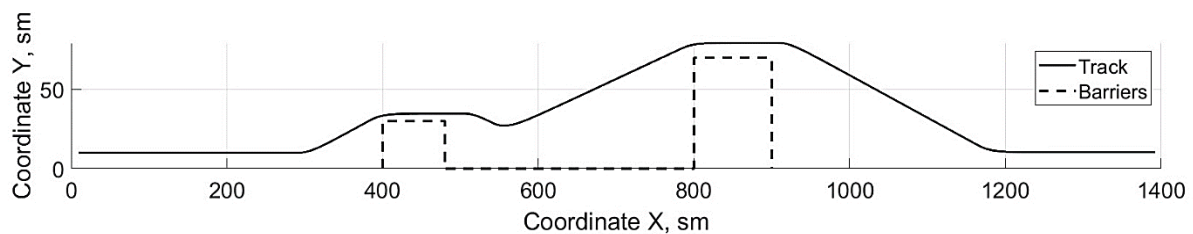
Application features of the VL53L1X laser rangefinder:

- fully integrated miniature module (25 mm \* 10 mm),
- emitter: invisible infrared laser with a wavelength of 940 nm (laser safety class 1),
- SPAD (single photon avalanche diode) receiver array with integrated lens,
- low power consumption microcontroller,

- sensor field of view (FoV):  $27^\circ$ ,
- I2C interface (up to 400 kHz).

To implement the collision detection and automatic evasion system, 3 laser rangefinders are required. The first rangefinder is located directly on the MR's course to detect and automatically evade head-on collisions with other MRs, people, technological equipment, or to maintain a specified distance in the keel of the group control. The second rangefinder is positioned to the left at a  $30^\circ$  degree angle from the centreline of the MR to detect an obstacle and determine if it can be avoided. The third rangefinder is positioned to the right at an angle of  $30^\circ$  degrees from the centreline of the MR to detect the obstacle and determine if it can be avoided. If there is no possibility to avoid the obstacle, the MR stops and gives sound and light signals.

The results of simulation of MP motion with obstacle detection and avoidance in MATLAB software are shown in Fig. 2.



**Figure 2.** MP motion simulation process with detection in MATLAB software.

The essence of the algorithm is to detect an obstacle, measure the distance to it, calculate the angle of rotation of the MR to avoid the obstacle. After avoiding the obstacle, the MR returns to the calculated trajectory.

Here is a complete overview of algorithm development in MATLAB:

```
clear; clear global; clc
global vg hzv hz0 xv yv tzv tz0 xv1 xvs yvs xvs1
hz0=10; hzv=5;
xc0=10; yc0=hz0; xc=xc0; yc=yc0; vg=10; tz0=0;
sd01=80; sd02=100; tzv=15*pi/180;
xv=400; xv1=xv+sd01; xvs=xv+400; xvs1=xvs+sd02; yv=70; yvs=50;
T=0:0.05:140; te0=0.0; A0=[te0; xc0; yc0; 0; 0; yc0];
options=odeset('RelTol',1*10e-4); [T,A]=ode45('Jump', [T], A0, options);
for i=1:size(T); H(i)=A(i,3);
    if (A(i,2)>=xv)&(A(i,2)<=xv1); A(i,6)=yv+hzv; H(i)=A(i,3)-yv;
end
    if (A(i,2)>=xvs)&(A(i,2)<=xvs1);A(i,6)=yvs+hzv; H(i)=A(i,3)-yvs;
end;
end
subplot(3,1,1); hold on; Fl_Tetta=plot (A(:,2),A(:,3),'-k')
D_Tetta=plot ([xv xv xv1 xv1 xvs xvs xvs1 xvs1],[0 yv yv 0 0 yvs yvs 0], '--k');
```

```

set( D_Tetta, 'LineWidth', 2 ); set( Fl_Tetta, 'LineWidth', 2 );
hold off; grid; xlabel('Coordinate X, sm'); ylabel('Coordinate Y, sm');
legend('Track','Barriers')
function F=Jump(t,x)
global vg hzv hz0 xv yv tzv tz0 xv1 xvs yvs xvs1
ot=2; A1t=4; A2t=4; lo=1; la=0; Log0=0; Log2=0; Log4=0; Logs0=0; Logs2=0;
Log1=0; Logs1=0; Duv=ot*vg*cos(tzv); Duvs=ot*vg*cos(0-x(1)); xt0=(yv+hzv-
x(3))/tan(tzv)+Duv;
xts0=(yvs+hzv-x(3))/tan(tzv)+Duvs; xts00=(yvs+hzv-hz0)/tan(tzv)+Duvs;
if (xv<x(2))&(x(2)<xv1); Log1=1; end;
if (xvs<x(2))&(x(2)<xvs1); Logs1=1; end
if or((x(2)<=xv-xt0),(x(2)>=xv1+xt0)); Log0=1; end
if or((x(2)<=xvs-xts0),(x(2)>=xvs1+xts0)); Logs0=1; end
if (xv-xt0<x(2))&(x(2)<xv-Duv); Log2=1; end
if (xv1-xt0<x(2))&(x(2)<xv1-Duv); Log2=-1; end
if (xvs-xts0<x(2))&(x(2)<xvs-Duvs); Logs2=1; end
if (xvs1+xts0<x(2))&(x(2)<xvs1-Duvs); Logs2=-1; end
if (x(2)<xvs-Duvs)&(x(2)>xvs-xts00); lo=0; la=1; end
tzad=(tz0)*Log1+(abs(asin((hz0-x(3))))*sign(hz0-x(3)))*Log0+(tzv*Log2);
tzads=(tz0)*Logs1+(abs(asin((hz0-x(3))))*sign(hz0-x(3)))*Logs0+(tzv*Logs2);
tzaa=atan((yvs+hzv-x(3))/(xvs-Duvs-x(2)));
Fey=max(tzad,tzads)*lo+max(tzaa,tzads)*la;
if abs(Fey)>=tzv; Fey=tzv*sign(Fey); end
if x(2)>xvs1+xts00; Fey=0; end
F=[ x(4); vg*cos(x(1)); vg*sin(x(1)); x(5); ot^3*(Fey-x(1))-x(5)*A1t*ot-
x(4)*A2t*ot^2; 0];
End

```

#### 4. Conclusion

The implementation of MR in manufacturing contributes to a significant increase in productivity, cost reduction, improved safety and flexibility of production processes. There are various path planning methods for MRs, including graph search algorithms, random sampling, and intelligent bionic algorithms. Each of these methods has its own advantages and limitations that need to be considered when selecting an approach for a particular task.

The developed algorithms were tested by means of modelling, which allowed to confirm their efficiency. To improve the safety of MR movement, it is proposed to use laser rangefinders, the determining parameters of which are distance, mass, reliability, and cost.

For obstacle detection the VL53L1X laser rangefinder based on the principle of time-of-flight (ToF) measurement from the ST FlightSense product family with the parameters; distance measurement range up to 4 m, measurement frequency up to 50 Hz, independence from the obstacle colour and surface reflection properties was selected. It is recommended to install 3 laser rangefinders to realise the collision detection and automatic evasion system. The topic of MR path planning and collision avoidance remains topical and requires further research, especially in the context of MR integration with other automated technological systems and increasing their reliability and safety.

## Note

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