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Navigation of Mobile Robot with Cooperation of Quadcopter

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***Abstract*—The simulation of a navigation heterogeneous group of robots; unmanned ground vehicle (UGV), unmanned aerial vehicle (UAV) through GPS, digital map and image processing using probabilistic roadmap method (PRM) are addressed throughout this paper. Having the capacity to navigate accurately is one of the major abilities of a mobile robot to effectively execute a variety of jobs including manipulation, docking, and transportation. To achieve the desired navigation accuracy, mobile robots are typically equipped with on-board sensors to observe persistent features in the environment, to estimate their pose from these observations, and to adjust their motion accordingly [1]. According to the scenario of the mission, UAV takes off from UGV, surveys the terrain and transmits Image terrestrial robot. UGV processes images, calculating the optimum trajectory method Probabilistic Roadmap with the help of GPS, and provide standalone navigate through the outdoor based on the calculated route. The group of robots is: UGV Belarus-132N and UAV Phantom-2 Vision quadcopter.**

Keywords—unmanned aerial vehicle; unmanned ground vehicle; heterogeneous group of robots; navigation; Probabilistic RoadMap method

I. INTRODUCTION

Robots are systems designed for playback of the motor and intellectual functions of man. It was evident that traditional machines have greater flexibility and ability to adapt to the various tasks, including changing environmental factor.

Currently, robotics have become a well-developed industry: thousands of robots working at various enterprises of the world, underwater manipulators have become an indispensable accessory of underwater research and rescue vehicles; space study is based on extensive use of robots with different levels of intelligence. Particular attention is paid to the automation of heavy, hazardous, tedious and monotonous work in a variety of industries with the help of robotics [2].

Today, however, experts in the field of robotics demonstrated roughly the same difficulty as those recorded in the past 30 years with computer developers. Due to the lack of common standards and platforms for the inventors of the robots they have to start the development of each new creation from scratch.

Yet, despite all the difficulties, those who are engaged in the field of robotics, from professors to businessmen and students are enthusiastic, reminiscent of the founders of the

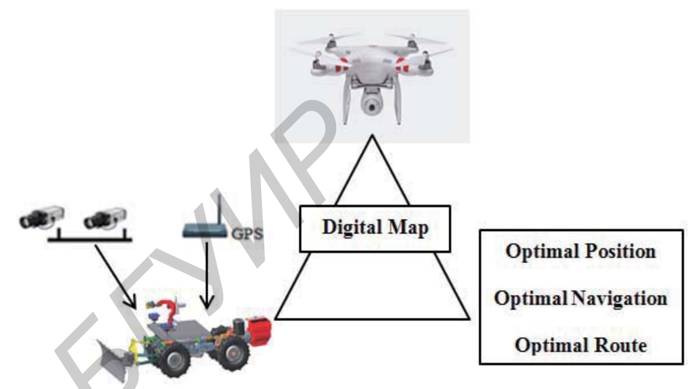


Fig. 1. System of cooperation of UAV/UGV for optimal path by using digital map of Quad-copter Mobile Robotic System.

Microsoft, when they were looking for ways to develop new technologies and dreamed that computers were available to everyone. And today, analyzing the trends of robotics development, we can imagine a future where robots will be indispensable helpers of people in their everyday lives. Perhaps mankind is on the threshold of a new era when PCs will go to the table and allow us to see, hear, touch and perhaps even manipulate objects from a distance.

Now the developers of systems using artificial intelligence can equip their inventions for GPS navigation system, video cameras, and many additional detectors, resulting in an increased power of modern robots.

Home robots and personal computers make life easier for the person. For example, office worker monitors the protection of your home, cleaning, unfolding washed laundry, supervising the work of domestic robots on the screen of your PC. In addition, the robots will be able to exchange information between themselves and the home computer [3].

To successfully navigate in space, robot system must be able to build a route to control the parameters of movement (to set the wheel turning angle and speed of rotation), to correctly interpret the information about the world, received from the sensors, and continuously monitor their own position.

Computer systems route planning is developed well enough. Originally they were designed for simple virtual environments, and the program, which simulates the action of the robot, to quickly find the optimal path to the goal in the two-dimensional mazes and rooms filled with simple obstacles. Along with faster processors, it became possible to generate motion path already on complex three-dimensional maps, and real-time.

This article discusses the modeling of heterogeneous groups Robots: UAVs and UGV. Algorithm of robot interactions is as follows:

1. UAV takes off from the UGV and moves over the environment, photographing it with the camera and transmitting image data to UGV.
2. UGV uses image maps, GPS navigation system, image processing system to calculate the optimal route for moving by using Probabilistic Roadmap Method (PRM).
3. UGV uses the results obtained in step 2 to move through the environment.

The aim of the article is to demonstrate the possibilities of modeling the interaction of air/ground robots in a realistic environment by using probabilistic Roadmap Method (PRM) as shown in Fig. 1 to achieve optimal positioning and navigation of UGV.

II. NAVIGATION

Robotics which may be defined as a field of science and technology, focused on the creation of robots and robotic systems for automating complex processes and operations, including those performed in uncertain conditions, to replace the person in the performance of heavy, exhausting and hazardous work [4].

Mobile Robot has a number of sensors to perceive its environment, a number of actuators (effectors) to act on the environment and management system that allows the robot to achieve its assigned goal in an efficient matter [5].

For navigation and position, mobile robot has to solve two problems to determine the current location, and build path of the upcoming journey, free from obstacles. An important role is played by the creation of navigation, allowing mapping system environment in which a Mobile Robot, to plan a route to the goal and avoid obstacles encountered on the way [6], [7].

Currently, in most cases, the robot managed by a human operator at the level of movements, while on the person side it requires continuous monitoring of the robot and the operational management of its activities. This approach is defined by the inability of the robot to make independent decisions and has a number of drawbacks. These include the need for continuous support of the organization and the link to the human operator (cable or radio link), which severely limits the scope of the robot.

The outdoor navigation system is designed for planning the route of the main robot. The main function of the machine at the same time is to recognize landmarks. An optoelectronic circuit that provides a solution to this problem consists of a lens with a variable focal length (zoom), an electronic unit, a control chamber mechanism that implements the rotation of the camera, as well as a landmark recognition system. Input signals are determined by a rough map of sight, visual models, landmarks, and description of the problem. The concept of the environment based on the map's scope known as (robot-road), the location of the robot, a sequence of location areas, throughout the movement route [8].

In order to navigate in its environment, the robot or any other mobility device requires representation, i.e. digital map of the environment and the ability to interpret that representation. Navigation can be defined as the combination of the three fundamental parts [9]: Self-localization (Positioning), Path planning, and Map-building.

Robot localization and positioning denotes the robot's ability to establish its own position and orientation within the frame of reference [10]. Path planning is effectively an extension of localization, in the sense it requires the determination of the robot's current position and a position of a goal location, both within the same frame of reference or coordinates. Map building can be in the shape of a metric map or any notation describing locations in the robot frame of reference.

The different applications of mobile robots have all in common an integral factor which is the quality that the robot can autonomously fill its task would depends strongly on the localization accuracy of the robot [11].

Mobile robots are typically equipped with sensors and equipment, like cameras, laser range finders or GPS, to observe their environment or combined with another method of navigation in order to eliminate errors in positioning.

One of the major tasks of autonomous robotics navigation is localization. In a typical outdoor environment, localization becomes a matter of determining the Cartesian coordinates (x,y) and the orientation θ.

III. DIGITAL MAP

Digital map is the process of which a group of data is processed, compiled and formatted into a digital image [12].

Traditionally, navigation maps were hard copies. The first digital map displayed only the data which was available as paper charts. And the first digital maps could not provide the pilot topographic, thematic or other additional information. Today, digital maps for navigation and tactical views are widely spreading out and supporting pilots with a wide range of additional information [13].

There are three types of digital maps: digitized map, database map, and hybrid map.

Digitized maps are made using an optical scanner, which considers information from the paper card and converts it into a digital sequence by using map recognition system [12]. Since the optical scanner reads the data points - pixels, thus obtained electronic map is a bitmap. The advantage of the digitized map is a high speed of manufacture and recognition.

Database map is a set of coordinates of objects with certain properties, such as color, length, thickness, etc. Base data card has higher precision and can be either two-dimensional or three-dimensional. Database map can be performed using a variety of sources, including the Internet.

Fig. 2. General view of Quad-copter Mobile Robotic System.

The Hybrid map is a combination of digitized paper maps and digital databases card data. Hybrid maps have higher accuracy than digitized paper maps, through the use of more information about the coordinates of certain objects in the database. Moreover, for calculating the coordinates of any objects outside the database, interpolation is used.

As previously noted, digital maps are used in the navigation systems of aircrafts or helicopters, and to show any other terrain that allows the pilot, for example, to plot. Satellite navigation systems GPS and GLONASS are provided within a pilot data to determine the current geographical coordinates, and the pilots using a paper map defines its position on the ground. It is clear that such navigation takes away a lot from the pilot time.

The navigation of digital maps using GLONASS / GPS / WAAS-sensors greatly facilitate the process of control of the aircraft, improve flight safety and provide a high accuracy [14]. Since the visualization of digital maps carried on board computer display, it gives you the opportunity to illustrate relevant information, such as the estimated time of arrival, distance to destination, altitude above the Earth's surface, etc.

IV. Representation of Navigation System

Mobile robots navigation is an actual problem of modern robotics. Navigation process comprises the following steps:

a) Preparation of environmental maps;

b) Correction of the trajectory of the robot;

c) Route planning (selection of the optimal path leading to the goal using PRM);

d) Management of local movements;

e) Bypassing the robot undesired sections of the route.

An algorithmic solution of these problems, obviously, should be based on information of the relief surface that may be known as pre-known information, be supplemented in the process of moving the robot. Local motion control by a known route is carried out on the basis of information about the nature of the surface in the near vicinity of the robot.

If we define the route of the sequence of reference points (sub-goals) movement, including the source and destination (target) position of the robot, the task of laying route involves the formation of a set of sub-goals and then selects such a subset that optimizes robot motion.

The process of lining the route of the robot movement precedes drawing environment maps. With the local movements of the robot are related tasks correction trajectories and avoid hazardous areas of the surface.

V. Quadcopter Mobile Robotic System

QMRS (Quad-copter Mobile Robotic System shown in Fig.1) is a real-time obstacle avoidance capability in Belarus-132N mobile robot with the cooperation of quad-copter Phantom-2. The function of QMRS consists of GPS used by Mobile Robot and image vision and image processing system from both robot and quad-copter and by using probabilistic roadmap method embedded inside the robot [15]. One of the main challenges is here to build environment representations that integrate aerial and ground data as shown in Fig. 2.

A. Description of UGV - Belarus 132N Mobile Robot

Unmanned Ground VehicleBelarus-132N is an international project (Belarus, Kazakhstan and Azerbaijan) consists of four-wheeled robot with dimensions 120 x 120 x 180 cm (length, width, and height respectively), weighing about 500 kg [16].

The UGR consist of serial chassis of tractor Belarus-132N and a video system; motion control system; onboard computer; communication systems with the control unit; attachments, such as blade and arm, master stream nozzle for fire-fighting as shown in Fig. 3 and Fig. 4.

B. Description of UAV – Phantom-2 Vision Quad-Copter

Phantom-2 Vision Quad-Copter is a lightweightquad-rotor equipped with acamera for photographing the land as shown in Fig. 4. The prototype of the UAV copter are small, light design elements weighing 1160g with max speed flight 15m/s with low power consumption. The image processing of Phantom-2 uses HD Video Recordingand save the image in JPEG picture formats.

VI. Navigation and Optimal Route of QMRS

There are many methods for robot positioning that can roughly be categorized into two groups: relative and absolute position measurements. QMRS (Quad-copter Mobile Robotic System) for positioning and navigation depends mainly on five factors as shown in Fig. 5: GPS of UGV, image processing of UGV, photographing of UAV, are creation of digital map based on image delivered from UAV and probabilistic roadmap method embedded inside UGR [17].

A. GPS of UGV

UGV has three modes of controls: remote, semi-autonomous and autonomous control. UGV has a server with geographic information system (GIS) supplied with a digital

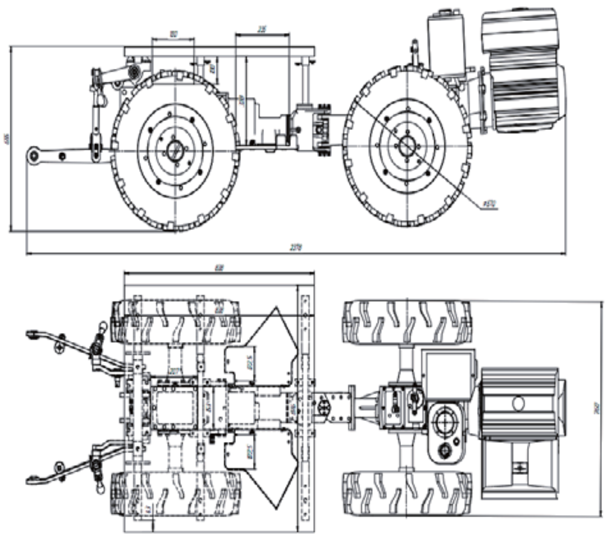


Fig. 3. General Scheme of mobileBelarus 132N platform.

Fig. 4. Generalview of the Belarus 132N Robotic System [15].

map for the site location. UGV has the GPS - receiver, which determines current coordinates on the map [17]. Data from the GPS-receiver is constantly updated and linked to a digital map and compared with image data.

B. Image Processing of UGV

The UGV robot is equipped with sensors and XY rotary video system used for surveillance operation in outdoor environment area and to control the movement and "to look around" during the stop, and other sensors of the current situation. Image processing systems receive data from a variety of cameras to determine the distance to an object (obstacle) with the captured output [18].

By using image processing system the UGV specify the point on a digital map, which must arrive, or reference point in the video frame in the direction of which it is necessary to move.

C. Photographing location from UAV

Due to the limited resources quad-copters batteries, its average flight time is 10-15 minutes. Initially, quadcopter is located on

Fig. 5. General view of Phantom-2 Vision Quadcopter.

the landing site of the UGV. Quad-copter takes off and moves over UGV at a height of 15-20 meters and surrounded area, photographing it using a camera and transmitting image data to UGV [19], [20].

D. Recreation of environment digital map

Initially formed a map of the working area of the robot, while the external environment is sampled, and each section comprising obstacle is associated with information about the type of obstacles. Mapping takes place simultaneously with the investigation of the environment [21].

Suppose that at the initial time the external environment has not been investigated, and the unmanned ground robot is in the free section of the center of 0 as shown in Fig. 7, which is considered the origin of the map [13].

Section area with numbers 1-8 is considered potentially passable. Scanning begins with the section number of section 1. If this is free, then the movement is performed in a medium in the direction of the first center portion as shown in Fig. 7. It is considered that the robot has moved to the center of the next available portion. The coordinates of the center of the plot are calculated by (1) and (2).

$$X_i = X_{i-1} \pm \Delta S \times \cos\alpha \quad (1)$$

$$Y_i = Y_{i-1} \pm \Delta S \times \sin\alpha \quad (2)$$

Where (X_{i-1} , Y_{i-1}) is the previous position of the UGR, ΔS is the displacement between two locations, αis the robot deviation angle from the x-axis.

In (1) the sign "+" is selected, if the X_i is located after $X_{i-1}$and the sign "-" if the X_i site is located before Xi_{-1}. In (2), the sign "+" is selected, if the Y_i is upper than Y_{i-1}, and the sign "-" if the Y_i is located lower than Y_{i-1} as shown in Fig. 8. Also, each section is associated with offset indexes on the coordinate axes, along with the center coordinates of the XY relative to the initial portion of 0 as shown in Fig. 7.

We use index portions as shown in Fig. 7 in order to arrange the storage medium in the robot map memory. Once struck robot information about the first portion of the map, it scans cross-sections 2, 3, ..., 8 moving counterclockwise around the perimeter area 0.

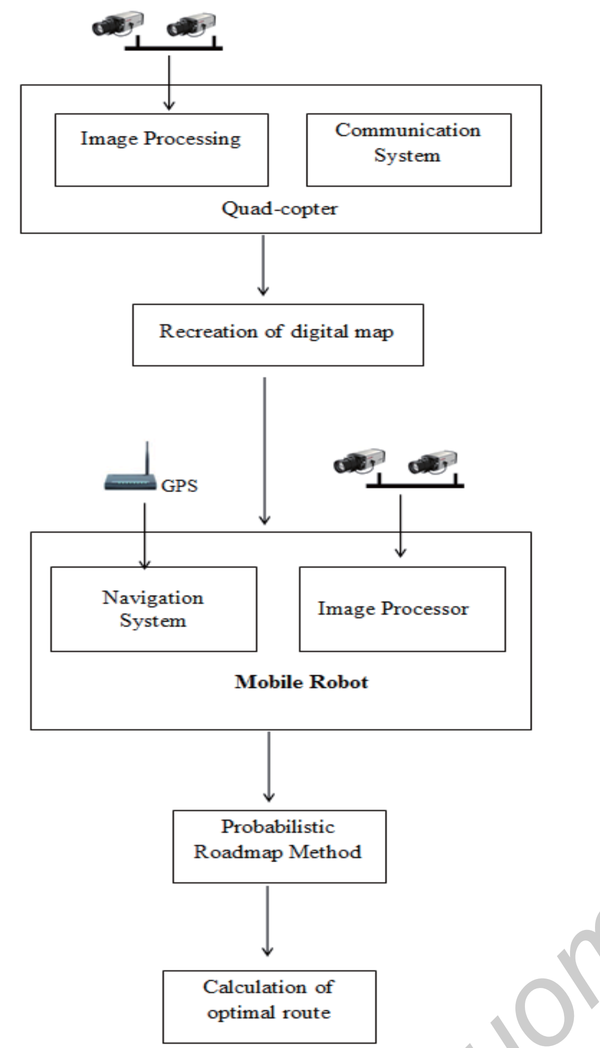
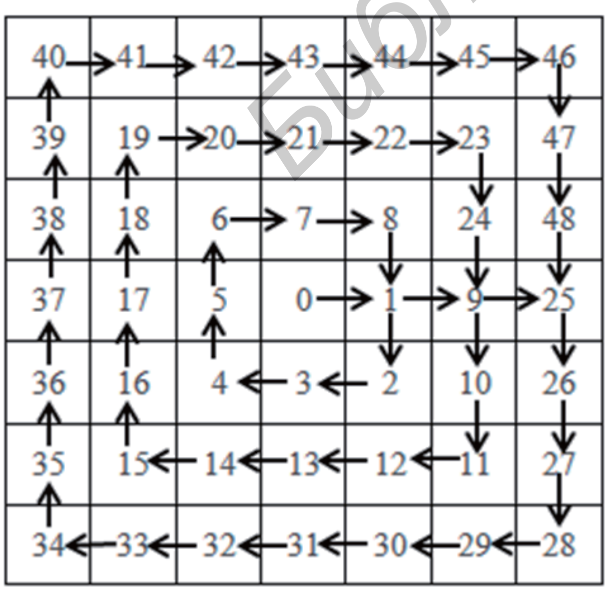


Fig. 6. Position and Navigation algorithm of Quad-copter Mobile Robotic System in order to select optimal path.



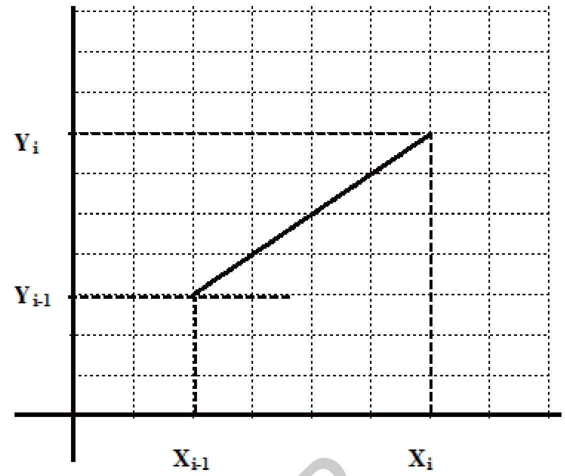


Fig. 7. The trajectory of movement of mobile robot for the map

Fig. 8. The movement of mobile robot from one point to another in XOY.

If any of these areas is occupied, the robot determines whether or not there's an obstacle or target and making site's information on the map. After scanning section 1-8 robot extends the research area and proceeds to scan sections 9-24, etc. This process continues as long as the external environments have no more unexplored area. After that, it formed a map of the working area in the robot's memory. After mapping environment, Robot must use it in the process of moving towards the goal. However, the resulting map cannot be absolutely accurate because of measurement error. Therefore, after each movement, the robot must perform update map positions.

E. Calculation of optimal path based on probabilistic roadmap method (PRM)

The algorithm of optimal route calculation is probabilistic roadmap method (PRM) [22] refers to the modern approaches in the field of trajectory planning. This approach is considered to be one of the leading algorithms at the planning movement, primarily for mechanical systems with many degrees of freedom in the environment with obstacles. PRM is a probabilistic method, highly effective, easy to implement, and applicable for various kinds of tasks related planning trajectory [23].

A probabilistic roadmap (PRM) is a network diagram of possible paths in a digital map based on free and occupied cells (obstacles) [24]. The PRM randomly generates possible cells (nodes) and creates connections (paths) between these nodes. The PRM algorithm uses the network of connected cells (nodes) to find the shortest obstacle-free path from a start to target location [25]. Probabilistic Roadmap Method proceeds in two phases [26]:

1. Pre-processing Phase to construct the roadmap
2. Query Phase to search given possible cells (nodes) and goal.

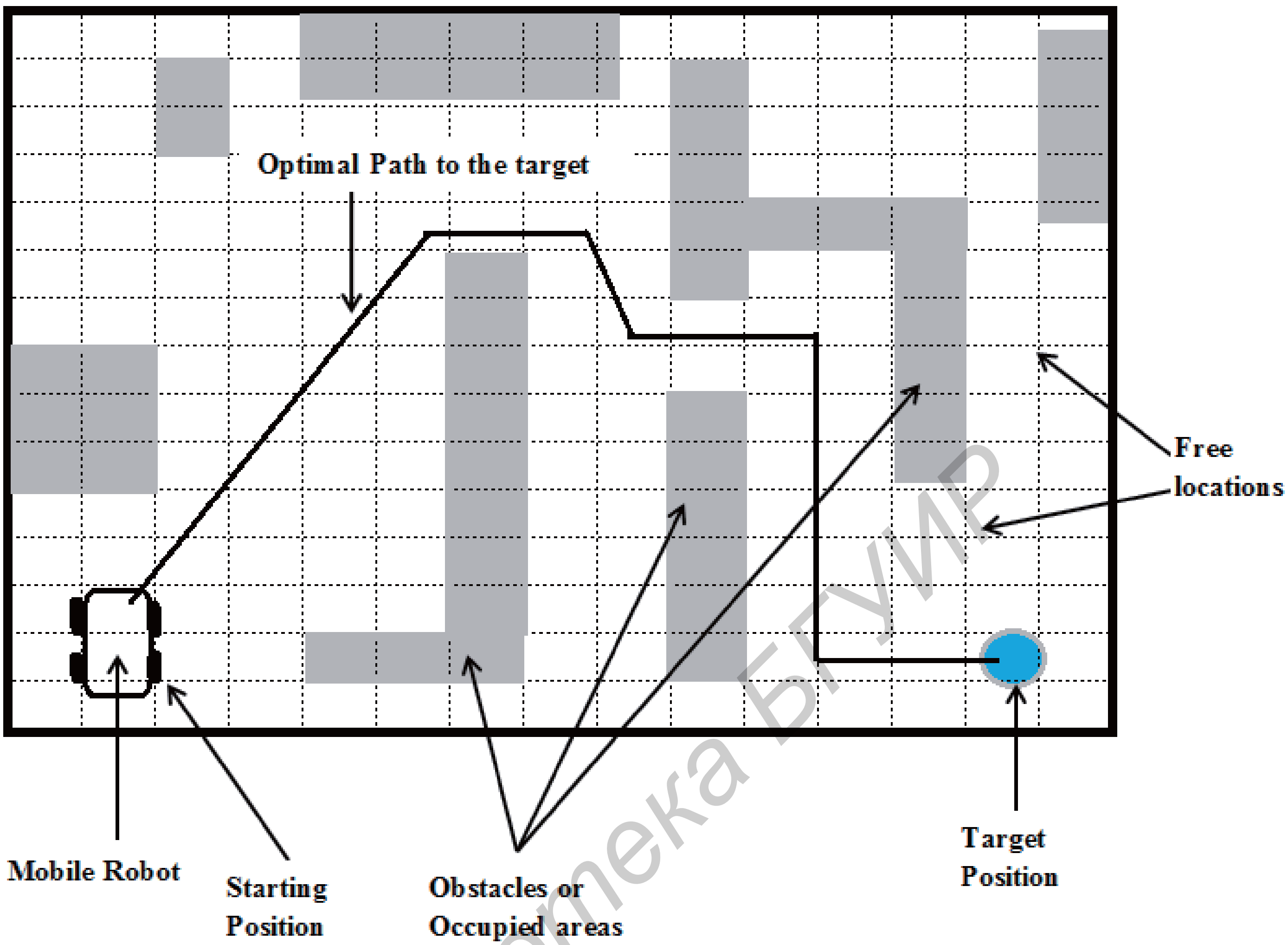


Fig. 9. Finding the optimal path of Mobile Robot.

Thus, the robot's task is to study the environment for the purpose of drawing up its maps and finding the target. As noted above, the mobile robot builds a map of the environment, moving from the starting point to the target by using probabilistic roadmap method [27].

The result is a map as shown in Fig. 9, where the white areas marked for free movement of the robot, gray-areas occupied by obstacles, and blue - the target location. Then, the robot is placed at the starting point of the movement. However, UGR's task is to find the optimal route (in the sense of path length) to the goal. The mobile robot reaches the target path which, ultimately, is considered out of the many routes as the most credible path that leads to set target.

The robot positioning was calculated using GPS and image processing from both mobile robot and quad-copter. The optimal route by the robot was calculated by using probabilistic roadmap method.

VII. CONCLUSION

In this paper, the positioning and navigation system for a Belarus-132N Mobile Robot was presented with the help of Phantom-2 Vision Quadcopter. QMRS achieves the following aspects:

i. Identifying the method involving the use of vision and image processing system from both robot and quad-copter.

ii. Analyzing path in real-time and avoiding obstacles based on the computational algorithm embedded inside the robot.

iii. Optimizing the efficiency and reliability of the whole system especially in robot navigation.

The development of intelligent mobile robots (IMR) for a variety of industrial and research purposes is playing a vital role in industry needs [27].

Our system consists of GPS system embedded inside the mobile robot, image recording by quad-copter, drawing up a map of the area, planning trajectories using probabilistic roadmap method, bypassing obstacles detected by the movement.

For future work there will be a plan to solve the following issues:

a) experimental studies of route selection;

b) the search for more efficient algorithms to achieve goals;

c) Representation of map in three-dimensional space;

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