Safe Path Identification in Landmine Area

Samarth Kapila and Parag Narkhede

Abstract Identifying the location of landmines is an important aspect considered in military and humanitarian operations in minefield regions. Advancements in technology allow to replace the sniffing animals with the autonomous machines/robots. In this paper, an autonomous robot equipped with a metal detector sensor is developed for the identification of the buried landmine. To successfully cross the minefields, a path planning algorithm is also proposed here. This algorithm requires mapping of complete navigation plane into the grid. During the motion at each location, the relative distances between the robot's location and destination along x and y directions are computed, and the algorithm decides the next movement. To check the feasibility of the proposed algorithm, it is ported on microcontroller platform and tested with the developed autonomous robot. The simultaneous checking for the presence of landmine and path planning provides the advantage of identifying the locations of landmines and a safe path to cross the minefields.

Keywords Autonomous robot · Landmine detection · Metal detector · Path planning

1 Introduction

Landmine is one of the most dangerous and widely used weapons in warfare. Landmines consist of highly explosive chemicals which explode either by contact or non-contact forces. As per the surveys, more than 100 million landmines are buried throughout the world. It is also reported that burying of landmines over 200 km of India–Pakistan border is planned by the Indian government [1].

Landmines are also laid down in the civilian and agricultural areas near international borders to increase the security of the country. The exploded landmines

S. Kapila · P. Narkhede (✉)
Symbiosis Institute of Technology, Symbiosis International (Deemed University), Pune 412115, India
e-mail: parag.narkhede@sitpune.edu.in

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have significant humanitarian and agricultural impacts. Hence, detection of landmine plays a vital role in the humanitarian and military operations. Use of animals like sniffing dogs and rats is the traditional way of landmine detection [2]. However, with the advancement in technology, automatic sensor-based systems are being employed in the landmine search operations. These sensor-based systems consider different characteristics of the landmine for detecting their presence.

Minefield generally consists of a number of rows of buried landmines and can be considered as a matrix of buried landmines. The successful and safe crossing of the minefields requires the knowledge of landmine locations. Knowing the locations of landmines, a safe area in the minefield can be identified and a path for crossing the minefield can be planned successfully.

Autonomous robots equipped with landmine detection mechanism are becoming important as the danger and manual detection cost is getting significantly reduced [3, 4]. Many researchers are putting their efforts to solve the problem of development of an autonomous robot for identification of buried landmine [4, 5]. Robots provide the advantage of efficient landmine search due to their lightweight. They generally provide low pressure in buried landmines and does not allow landmine to get triggered. Landmine detecting COMET-II and COMET-III robots with six degrees of freedom are developed by Kenzo Nonami [6].

This paper considers the problem of identification of a safe path in the minefields. The considered problem is majorly divided into two parts: (1) identification of landmine location and (2) planning of the safe path in the minefield. The landmine detection is addressed by developing the metal detector-based system, whereas a safe path identification (SPI) algorithm is proposed to solve the problem of path planning. The paper discusses the development of the prototype of the autonomous robot equipped with metal detector sensor and SPI algorithm.

The complete paper is organized as follows: Sect. 2 provides the different landmine detection technologies along with path planning techniques. Section 3 provides the hardware and software methodologies followed in the paper. Section 4 provides the results, and Sect. 5 concludes the paper.

2 Literature Overview

2.1 Landmine Detection

A wide research is currently going on in the detection of landmines. Researchers are experimenting on a number of different techniques to identify the presence of landmines.

Metal detector (MD) sensor is employed by many researchers in landmine detection application [2, 4, 7]. MD sensor consists of a coil which is responsible for the generation of electromagnetic field in the nearby area. The presence of metallic object affects this induced electromagnetic field creating a signature for landmine detection [8]. Nowadays, metallic mines are getting outdated and plastic mines are being developed. Even the plastic mines contain some metallic part. Hence, identifying the metal-based detection can serve for landmine detection.

Ground-penetrating radar, thermal imaging, acoustic and millimetre waves are also used in the landmine detecting systems [9–11]. However, their performance is highly dependent on the environmental conditions. Also, the systems equipped with these detection technologies are larger in size and may not provide a low-cost solution [12]. MD sensor is cheaper and small in size and weight and hence can be the reason for being popular for landmine detection. Abeyanake et al. developed a Kalman filter-based landmine detection system employed with an array of metal detector sensors [7]. They have observed that system with multiple sensors provides better results as compared to the system with single sensor.

2.2 Path Planning

Path planning is a technique that decides a possible way from source to destination. It can basically be of two types: global planning and local planning [13]. Global planner considers the previously available knowledge of the environment and finds the optimal trajectory. However, in practice, they are computationally expensive. Local planners plan only a few steps in the near future based on current sensory data. Such planners require less computational power and are good choices for the robot with the limiting sensing abilities. However, due to limited planning, the robot may get stuck at some location and not reach the target. Thus, the problem of global convergence to the destination needs to be addressed while considering a local planner system.

Lots of approaches for robot path planning have been proposed and implemented in the literature [13–15]. Grid-based navigation [13] and interval-based navigation [15] are two of the widely used path planning techniques. An important distinction between them is in how they represent the real world.

Gonzalez et al. discussed the various motion planning techniques employed for autonomous robots [16]. They have provided the comparative analysis for the graph-based planners, sampling-based planner, interpolating curve planners and numerical optimization planners. Interpolation-based search algorithms are the most widely used techniques due to their enhanced ability to generate required coordinate points with the help of GPS data. When it comes to real-time implementation, graph-based techniques are preferred due to their fast search operations.

Grid-based navigation is extensively studied and explained by Balch [13]. In grid-based navigation, a complete navigation plane is divided into a grid, generally referred as occupancy grid, and each block of grid is logically numbered in the form of (x, y) coordinates, where x and y represent the coordinates along x and y directions, respectively. When a robot moves, its location in terms of (x, y) coordinates is updated. When the robot is present at a location (x, y), then in a grid, its position [x, y] is marked as full. If a robot moves in forward direction, then the new location is indicated by (x, y+1) and in a grid [x, y+1] is marked as full and [x, y] is marked as empty. The grid's resolution refers to how large an area in the real world is represented by one cell in the grid.

The performance of the grid-based navigation planning depends on the size of each block in grid. Larger the size of the block less is the resolution, which may result in less optimal path. So, the selection of resolution is an important aspect in grid-based navigation. The block size should be decided based on the accuracy of the position sensors and robots movement speed. High-resolution grid may represent accurate positions of the robot and obstacles, helping the optimized trajectory planning.

3 Design Methodology

This section discusses the hardware and software designs of landmine detection robot along with the design of safe path identification algorithm.

3.1 Landmine Detection Robot

The basic block-level description of the landmine detecting autonomous robot can be depicted as in Fig. 1. It consists of metal detector sensor and GPS unit as input devices, a processing unit and motors as output devices. Sunroms 1139 metal detector sensor is used to identify the metallic objects/landmine buried underground. The sensor provides the digital output when metallic object comes under its proximity. This sensor requires 5 V, 50 mA power supply for the operation. The digital signal obtained from metal detector is provided to the digital pin of Arduino for alarming. A GPS module is used to locate the position of the robot in the grid. Arduino Uno board is used for carrying out necessary computations and taking the decision for safe motion. Uno board is equipped with ATmega 328 microcontroller which is a low-power, 8-bit microcontroller and is widely used in the robotic applications. The motion of the robot is controlled by DC motors connected to it.

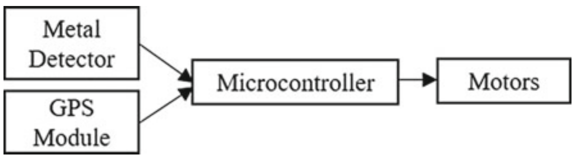

Fig. 1 Block diagram of landmine detecting robot

3.2 Safe Path Identification Algorithm

Algorithm plays an important role in robotic development. SPI algorithm focuses on the planning of safe path in the minefield. The stated algorithm is developed with consideration of few assumptions listed below:

- The size of robot is equal to the size of each block in grid.
- The minefield contains only landmines, and there are no other obstacles present.
- If landmine explodes, then the size of affected area is same as size of a block of a grid.
- The robot can move only along any one axis at a time.
- In one step, robot's location is only incremented by 1.

With these assumptions, the safe path identification algorithm can be stated as:

Step 1 Provide the destination coordinates to the robot (d_x, d_y).
Step 2 Measure the coordinates of robot using GPS, and locate them into considered grid let (s_x, s_y).
Step 3 Find the relative distance between source and destination along x and y directions as

$$\Delta X = d_x - s_x; \quad \Delta Y = d_y - s_y \tag{1}$$

Step 4 Find the fractional ratios along x and y directions as

$$\Delta x = \Delta X / HCF(\Delta X, \Delta Y); \quad \Delta y = \Delta Y / HCF(\Delta X, \Delta Y) \tag{2}$$

where HCF stands for highest common factor.
Step 5 If $\Delta X > \Delta Y$, then move the robot along x-direction; otherwise, move the robot along y direction and update the robot location in (s_x, s_y).
Step 6 Identify the presence of landmine using metal detector.
If present, note the location as danger and revert the robot to recent safe location.
Else note the location as safe, and repeat from step 2 until robot reaches destination
Step 7 The safe path can be given by combining all the points indicated by safe.

The SPI algorithm determines the safe path in the minefield which can be used by humans, militants and vehicles to safely cross the minefields. The computation of fractional ratios provides the advantage of identifying the possible short path between source and destination.

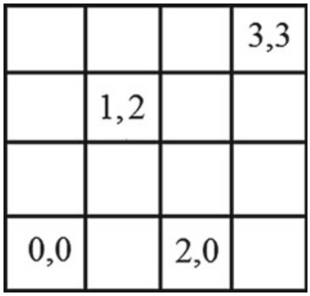

Fig. 2 Coordinates allocation in grid

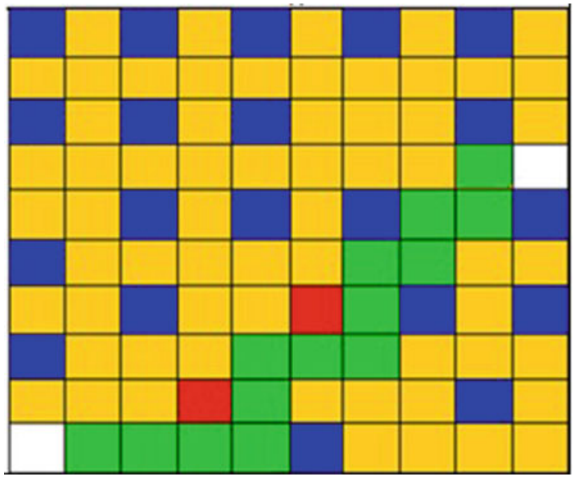

Fig. 3 Simulation results for SPI algorithm

4 Results and Discussion

The development of landmine detecting autonomous robot is carried out in two phases. In the first phase, SPI algorithm is developed in MATLAB and offline simulations are carried out to check its feasibility. In the second phase, the SPI algorithm is ported to the real hardware platform and tested with autonomous robot.

For the offline simulations, a grid of 10×10 size is taken into consideration. The locations in the grid are logically numbered as coordinates in two-dimensional matrix. A sample 4×4 grid is shown in Fig. 2.

The offline simulation result of the SPI algorithm is shown in Fig. 3. In the grid, landmines are assumed to be present at some locations; locations are shown in blue, whereas the white blocks represent the source and destination. Yellow blocks represent the safe blocks in grid. In Fig. 3, (0, 0) and (9, 6) are considered as starting point and destination points, respectively. It can observed that distance along x-direction (ΔY) is more than y (ΔY), and hence, the robot's motion is started along x and robot reaches to (0, 1). At this point, it checks for the presence of landmine, also calculates, and then decides the next movement and the process continues. When

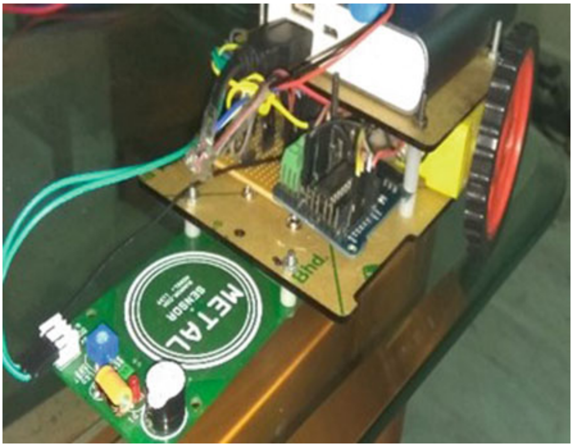

Fig. 4 Developed autonomous robot

robot reaches (3, 0), ΔX is equal to ΔY; i.e. distances along x and y are same and hence change the direction to y and move to point (3, 1). But at (3, 1) landmine is detected and robot returns back to recent safe location, i.e. (3, 0) and continuous motion along x. Blocks in green colour represent the safe and short path identified by the proposed SPI algorithm. Landmines identified by robot while moving from source to destination are denoted by red blocks in grid. During the simulations, it is assumed that width of path and the width of robot is same; also, there does not exist any type of obstacles in the path.

The hardware setup of the SPI algorithm-enabled autonomous robot is shown in Fig. 4. During hardware testing, the grid is prepared on a floor and small metal parts are used in the place of landmines. From the results, it can be stated that the proposed algorithm is suitable to find the safe path while travelling from the source location to destination which can be used to cross the region where landmines are buried.

5 Conclusion

The development of the metal detector-based landmine detecting autonomous robot is discussed in this paper. The path planning algorithm featured with safe path identification is also discussed in this paper here. The proposed SPI algorithm is ported on hardware prototype developed with an autonomous robot. The tests are carried out with offline simulations and using developed autonomous robot. The considered metal detector sensor was able to successfully identify the metallic objects; however, it is unable to discriminate between the landmine and metal objects. The proposed algorithm also provides the shorter path between source and destination. The future work will focus on removing the assumptions considered while developing the SPI algorithm to get more robust results.

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