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Modified Virtual Semi-Circle Approach for a Reactive Collision Avoidance of a Mobile Robot in an Outdoor Environment

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Abstract. There are numerous numbers of methods that have been introduced to the Unmanned Ground Vehicle (UGV) to find its optimal path. The purpose of this paper is to navigate a cost effective UGV known as MG-TruckS with optimal path planning in an outdoor environment. A Modified Virtual Semi Circle approach is proposed based on situated-activity paradigm. This approach is divided into two phase to compute a free collision path planning; detection and avoidance phase. Implementation of five ultrasonic range finder sensors with a very small blind zone created on purpose and the formation of three layers of influence zone shows the optimized path planning without making any unnecessary obstacle avoidance being computed.

Introduction

Path planning can be described as the task of navigating an Unmanned Ground Vehicle (UGV). UGV is a vehicle that operates while in contact with the ground and without human presence on board. UGV can be an autonomous vehicle which is capable to sense their environment on its own or can either be remote-guided vehicle [1]. UGV is widely use in military and industry purposes to facilitate human task especially in surveillance issues [2]. An autonomous UGV must be able to reach its predetermined target position with free collision avoidance path planning. Collision avoidance is the process of directing a robot's path to overcome expected and unexpected obstacles while navigating [3]. The UGV has to generate feasible and safe trajectory from the current robot position towards goal position [4]. Local path planning navigation directly uses the sensor's information in the command that control the motion without constructing a global map. Therefore, it suits to navigate UGV in dynamic environment with the existence of moving obstacles.

Recently, numbers of researches regarding local path planning is increasing gradually. Artificial Potential Field (APF) is one of the path planning algorithms that widely used by most researchers in local path planning. It was first proposed by Khatib [5]. The robot will navigate in the workspace as a particle that moves under the influence of potential field generated by the target and the obstacles. The target will generate attractive potential while the obstacles produce repulsive potential to keep the robot away from the obstacles [3]. Through decades there are many researchers propose the improvement of APF to overcome the drawback from the conventional approach [6][7]. The concept of Potential Field was then implemented in one approach entitled as Virtual Force Field (VFF). The combination of certainty grid and Potential field was used to construct the path planning for a mobile robot [8]. The improvement of this method is widely used too but certainty grid concept used for representation of (inaccurate) sensory data about obstacles and Potential Fields hinges on the principle of repulsion and attraction forces where obstacles exert repulsion force and the target exerts an attractive force on the robot [4].

A classic design paradigm known as situated-activity paradigm has an advantage that employs a "divide and conquer" strategy to reduce the difficulty of the main task in path planning problems. It is a design methodology used to define each set of situations that describe relative state and problem entities, and on association with each situation [9]. The work develops by Minguez and Montano in [9] addressed a reactive collision avoidance method by adapting the situated-activity paradigm which is called as Nearness Diagram (ND). The next action was described by each situation. Five situations have been defined; Low Safety 1(LS 1), Low Safety 2 (LS2), High Safety Goal in Region (HSGR), High Safety Wide Region (HSWR) and High Safety Narrow Region (HSNR). This work was developed by Joseph and Francesco with an approach known as Nearness-Diagram+ (ND+) by adding one more situation which is Low Safety in Goal Region (LSGR) [10]. Another new approach was developed based on situated-activity paradigm is Virtual Semi-Circles (VSC) approach proposed by Tang S.H et.al [4]. Four modules were developed; division, evaluation, decision and motion generation for a mobile robot to successfully navigate in cluttered, dense, and complex environment.

This paper proposed a new approach of reactive collision avoidance based on VSC approach which mainly using the data from sensory information to execute free collision with no presence of unnecessary obstacles avoidance path planning. In this research, the UGV will be known as Mobile Guard UGV-Truck Surveillance (MG-TruckS). The MG-TruckS is constructed for surveillance purpose.

Modified Virtual Semi Circle Method (MVSC)

The path planning approach which gains information data from the sensors is one of the safe alternatives for UGV to navigate in a free collision avoidance path. The MVSC is an adaptation from the VSC method [4] with new approach that keeps its four modules: division, evaluation, decision and motion generation. MVSC divided the path planning into two phases which are obstacle detection and obstacle avoidance. In detection phase the first 2 modules will be implemented: division and evaluation, while in the avoidance phase involves the other 2 modules: decision and motion generation.

A. Obstacles Detection Phase

i. Division

The MG-TruckS is equipped with ultrasonic range finder sensors. The maximum distance for a detection of the ultrasonic range finder sensor is 3 meter. The ultrasonic range finder sensors have significant price compared to other type of sensors. Furthermore, it has a narrow angle range of detection which is30^{o}. Hence, the actual area of the obstacles detection can be easily defined. This will lead the MG-TruckS to avoid the obstacles successfully without making any unnecessary obstacles avoidance.

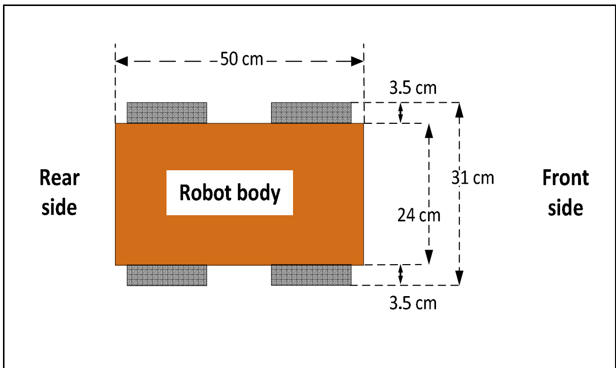

Figure 1: Top view of the MG-TruckS

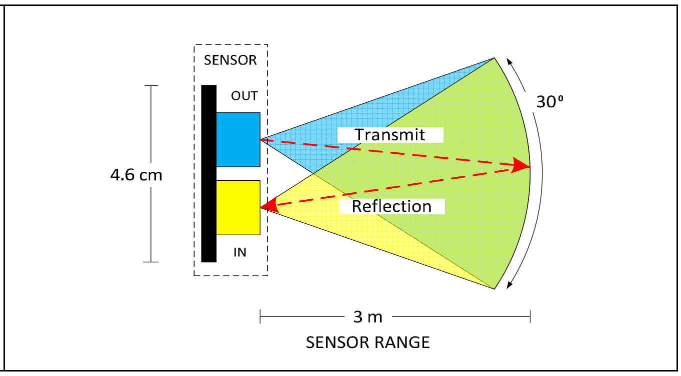

Figure 2: Sensor range of an ultrasonic range finder sensor

The MG-TruckS is equipped with five ultrasonic range finder sensors. A sensor was placed at the front of the MG-TruckS. It will have five subspaces which are: Bottom Left (BL), Top Left

(TL), Centre (C), Top Right (TR) and Bottom Right (BR). Thus, the position of the obstacles will be defined by the subspace as shown in Figure3:

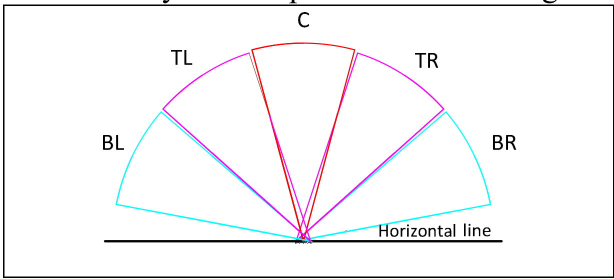

Figure 3: Five Subspaces of ultrasonic range finder sensors

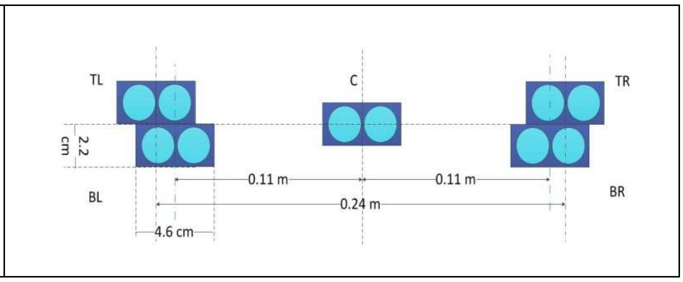

Figure 4: Front view of the arrangement of ultrasonic range finder sensors on the MG-TruckS

Figure 4 shows the front view of the five ultrasonic range finder sensors on the MG-TruckS. MG-TruckS will be equipped with ultrasonic range finder sensors for forward-looking motion. The array of five ultrasonic range finder sensors is arranged in order to create 160° of total angle sensor range. Therefore, the Mg-TruckS still have a broad view of forward-looking motion. The arrays of five ultrasonic range finder sensors are shown in Figure 5. Each of the sensors is divided into 6 regions in 0.5 m, 1m, 1.5m, 2m, 2.5m and 3m from its centre. These will represent the actual region of the obstacles when the MG-TruckS detects the obstacles. The small region of sensor will execute the accuracy of the distance in obstacles detection.

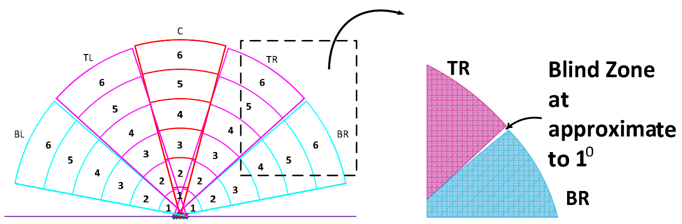

Figure 5: Array of five ultrasonic range finder sensors and subspaces

There exists a blind zone in the sensor array. It only involves the range of region five and region six in the sensor array with a very small angle of blind zone which is approximate to 1°. The existence of the blind zone helps to solve overlapping data issue in obstacle detection. By implementing Isosceles Triangle Theorem, the maximum distance of the end of the blind zone, is nearly 1.75cm. Since the value is small, it shows that the blind zone area is significantly ideal.

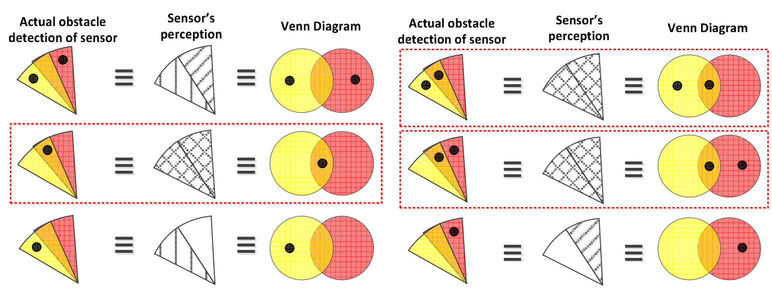

Figure 6: Overlapping issues on ultrasonic range finder sensors

The blind zone area will overcome the overlapping data problems in obstacle detection as shown in Figure 6. Overlapping sensor will cause the detection phase to define the feasible region as the non-safe navigable path.

ii. Evaluation

This module describes the MG-TruckS and obstacles relation within the evaluation region. Each region ofthe sensor arrays will be labelled by numbering it from region 1 to region 6. The region with high value represents the higher distance from the UGV to the obstacle detection. The obstacles detection with grey region is presented as in Figure 7. If UGV detects the lowest value region such as in sensor C, region 3 was detected. Therefore, region 3 to region 6 will be defined as not navigable region. The next step is to decide the navigable path for the UGV to compute its new trajectory it the path planning.

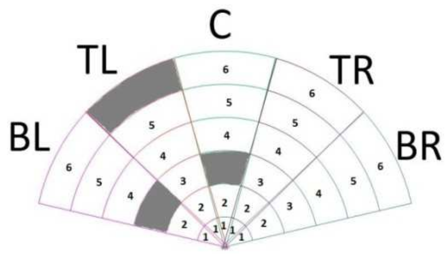

Figure 7: Evaluation of the robot's work space region

B. Obstacles Avoidance Phase

iii. Decision

The new three layer zone will be introduced here. The influence zone will be constructed after the detection purpose as shown in Figure 8. The first layer from the obstacles is labelled as first influence zone is 1 m, followed by second influence zone within 2 m, and 3 m as for the third influence zone from the nearest obstacle's surface. The UGV will navigate from influence zone three towards influence zone one in order to reach the target position. The position of the MG-TruckS will be defined when it makes its new trajectory based on the following case:

Case 1: Influence Zone 3

When distance of the obstacles is longer, the angle for direction of motion will be smaller.

Case 2: Influence Zone 2

When distance of the obstacles is shorter, the angle for direction of motion will be larger.

Case 3: Influence Zone 1

The angle for steering motion of the MG-TruckS will be the smallest one, which will navigate the MG-TruckS to be nearest to the obstacles.

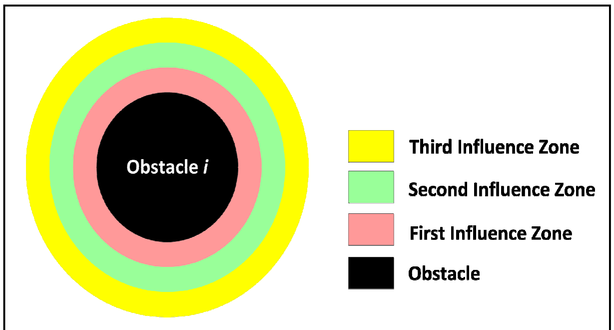

Figure 8: Formation of Influence Zone zone

Influence zone will always be created at minimum distance point of detection from the ultrasonic range finder sensor.

iv. Motion Generation

MG-TruckS generates a new trajectory and continue it motion after decision has been made through each case. Direction of motion (θ) is equal to the angle between y-axis of the MG-TruckS position with the safe region. The value of the direction of the motion changes based on the distance of the obstacles detection and the position of the MG-TruckS in the influence zone.

Result

The experimentation result shows the effectiveness of the proposed approach to execute the shortest path planning in term of time costing, length of path, smoothness of the velocity and safely reach the goal position without any collision. The result is based on the graphical approach with the MG-Trucks equipped with five ultrasonic range finder sensors for distance measurement. The start and the goal positions are static in completely unknown environments. Figure 9 shows the result of the path planning of the MG-TruckS from start position labeled as S toward the goal position labeled as G with nearness detection by robot sensors at current position.

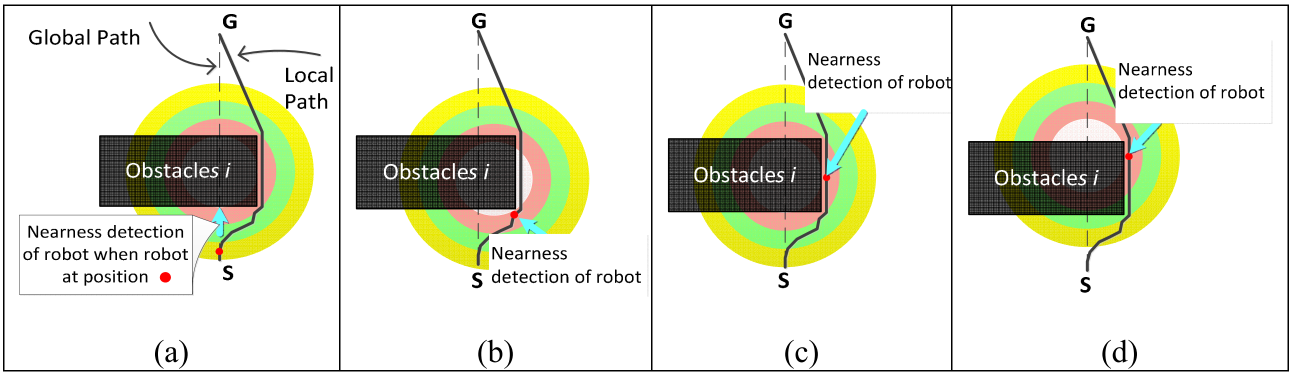

Figure 9: Some path planning motion of the MG-TruckS from (a) to (d) toward G

Conclusion

This paper presents a reactive collision avoidance method that describes each of the situations and simplifies the difficulty of the path planning by divide and conquers strategy with situated-activity paradigm. The Modified Virtual Semi Circle is a new approach that implements the multiple layers of influence zone for each obstacle detected with new arrangement of sensor to be placed to the mobile robot. Since the approach is very simple, it requires low computational cost and do not demand a very large memory. The path planning for the mobile robot shows that it does not makes any unnecessary obstacles avoidance. Hence, the path planning of the MG-TruckS is optimized with shortest path taken.

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