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The Swarm-based Exploration Algorithm With Expanded Circle Pattern For Searching Activities

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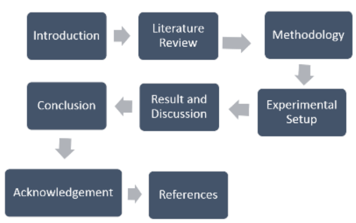
Graphical abstract



Abstract

Searching Mechanism is an important technique that is usually used by Search and Rescue team to find people especially victims for natural disasters. In this paper, we propose an exploration algorithm using quadcopter in simulation to discover an unknown area that is based on the expanding circle pattern for searching activities. Expanding circle searching pattern is a circular search procedure that is conducted by a series of distances around a fixed reference point, which can be used for unknown area exploration. The simulation is implemented in a swarm-based environment as it can increase the performance of robots for exploration compared to the non-swarm based environment. Based on the initial simulation result, the swarm-based exploration algorithm with the expanding circle pattern can maximize the searching area covered if compared with only having individual searching robot.

Keywords: Swarm-based exploration algorithm, searching, swarm robots

1.0 INTRODUCTION

Currently, natural disasters become a main problem around the world. The effect of natural disaster or another kind of disaster (plane crashed) can give serious problem to people. Search and Rescue team usually do the search activity as the first reaction for the victims and then they will continue by rescuing them. There are different types of technology that have been developed and implemented to support the Search and Rescue team. The unmanned aerial vehicle (UAV) is a kind of vehicle that is usually chosen that can operates without a human pilot aboard. As an example, [1, 2, 3, 4, 5, 6] has proved UAV can be used to cover large areas searching for targets, move rapidly or see through such obstacles as buildings or fences that cannot be done by UGV.

The search mechanism is a technique that is used to explore certain area and detect certain object for some purposes. In Search and Rescue context, there are two types of searching which are one-sided search problem and two-sided search problem. The first one is one sided search problem that is determined only when the searcher that is looking for the object. There are two types of one-sided search problem which are stationary search object where the object does not move when the searching activity is conducted and moving search object where the object do move when the searcher is looking for them. The second one is two-sided search problem where the searcher and the object give some response to the search activity. There are two types of two sided which are the cooperative searches where the searcher and the object is looking for each other and non-cooperative searches where the object attempt to avoid the searcher.

In searching activity, there are four elements must be completed to do a searching. They are object identification to detect object, path planning to determine which area for next exploration, navigation system to manage the movement of quadcopter and the altitude while detecting object and exploration to discover an unknown area for finding object. Those four elements should be completed because those has main role for finding object as a main result of searching activity

Moreover, swarm-based technique is considered in this research because of its advantage that is mentioned in [7] which are swarm robot can perform more efficiently, actuate at different place simultaneously, have wider range of sensing than non-swarm robot, accomplish certain goal which are impossible for non-swarm robot. Besides that, the expanding circle is implemented here because the expanding circle pattern can make a pattern for exploration to be spread evenly.

Therefore, in this paper, we develop an algorithm for exploration in quadcopter so that this quadcopter can explore an area effectively and efficiently based on expanding circle pattern in the proposed exploration algorithm in searching activity to find any object (victim) that need help as soon as possible before the SAR team get them.

2.0 LITERATURE REVIEW

Exploration is the act of searching for the purpose of discovery of information or resources. Exploration of unknown environments has become one of the interesting problems in robotics. This work requires a robot to explore and at the same time to learn the covered area so as the final result, the area can be fully identified and recognized. A multi-robot system has given some contribution in this research field.

[8, 9] has shown some experiment about the exploration algorithm. In [8], a decentralized strategy for cooperative robot exploration has been developed. A simple and decentralized cooperation mechanism become the basic idea of this method. Each robot moves towards areas that appear to be unexplored by the rest of the team on the basis of the available information. However, [9] offer a new method inspired by [8]. Thus, [9] utilizes four state which are explore, meet, sacrifice and relay. This method is compared and the result shows that the improvement of using the state of meet, sacrifice and relay can explore a greater percentage of the map (5% to 18%). This method maximize the efficiency of exploring with unreliable communication and limited energy battery that can be predicted as well. However, it is just for small-scale environment, not for extreme environment and there is possibility that the robot cannot go back to the base station.

The similar idea is also described by [10] where the robots will cooperate to store information of covered area. Role-based autonomous exploration algorithm is proposed by [10]. In this method, there will be two mobile robot and each of them is assigned one of two roles at the beginning of exploration and do not change. The two roles are explorer and relay. However, [10]'s method has a limitation of communication and it is limited by static team hierarchy and maintaining them can lead to long travel to rendezvous point.

So far, it can be seen that those algorithms can lead to long travel to tryst point or getting stuck at certain point where can result inefficient exploration. Therefore, [11, 12] has tried to solve this kind of problem. These two works will be explained below.

First of all, [11] introduced a hybrid/deliberative approach to the multi-robot for exploration problem. Basically, this approach rely on the concept of expected safe zone inspired the concept of safe zone implemented by [13, 14] and gateway cell. Moreover, the hybrid/deliberative approach has some advantages such as the avoidance of local minima, the reactive process runs in a delimited period of time caused by the expected safe zone concept and all these show the robustness of the algorithm. However, usually, if more robot is implemented so the result should better but here, it increases error because too many robot must cover a small area travel in shorter path, more time needed in the change zone state for coordination.

Besides that, a simple exploration algorithm introduced by [12] that combines a behaviour-based navigation with an efficient data structure to store path taken. The proposed algorithm implement four different behaviours and a resultant emergent behaviour. The good things are it can cover a large open space and it never gets stuck nor spends unnecessary time because of the use of hash table. Unfortunately, it depends the communication with other robot so there is limitation in distance and the quality of map is also not good.

Moreover, [15] introduced a cooperative approach for multi-robot exploration that adopted the frontier-based algorithm. The optimal frontier will be selected by evaluating information gain and navigation cost and considering the communication range. Thus, the robot team calculates the set of frontier cells and select the candidates from this set. Eventually, the exploration of unknown environment can be converted into a problem of multi-stage trajectory planning in known environment which consist of two sub-processes including avoiding to disperse the robot team and tracking to synchronous rendezvous for multi-robot. The efficient and distributed exploration give some benefit so it can minimize the navigation cost. However, since it calculates local destination without enough information, it needs more exploration step. It does not consider the motion and measurement uncertainty and has limited communications.

Some works about the exploration method is under communication constraint. [16] Proposes an algorithm that is claimed as the original way to formalize and solve the issue that relies on distributed constraint satisfaction problems (disCSP) which are an extension of classical constraint satisfaction problem (CSP). There are five states implemented on this algorithm. All these five states will be repeated until no more unexplored area. Every robot must exchange their local map to each other to build global view of the environment in order to detect those five states. It guaranties the connectivity between all members, it is easier for deadlock detection and it decreases the duration when adding the number of robot. But, when robot is added, the team spends more time avoiding each other than exploring, the size of disCSP also increase so requiring more messages. The algorithm is asynchronous so the delay occurs when exchanging messages.

After observing at those exploration algorithms, final problem lead us to [16]'s problem. Where robot is added, more time is needed to avoid each other than exploring time itself. It means that the distribution or deployment of robots can give impact to the efficiency and effectiveness of exploration period.

It can be summarized that the use of multi robot in the exploration can give better results in term of distributed of robots. In other words, the large environment can be covered by multiple robots with less duration in finishing it.

3.0 METHODOLOGY

In this section, the methodology will be explained. First of all, the Figure 1 shows the flowchart of expanding circle that will be used in this research. Variable a and b are assigned to be 0 that will be use later in equation (1) and (2). After that, the robot position is obtained for x and y coordinate. Then the value of x and y is assigned based on the equation (1) and (2) and the value b is updated. After the implementation of equation for x and y, current coordinate is compared with the expected coordinate. The program will be always running as long as the current coordinate is less than the expected coordinate.

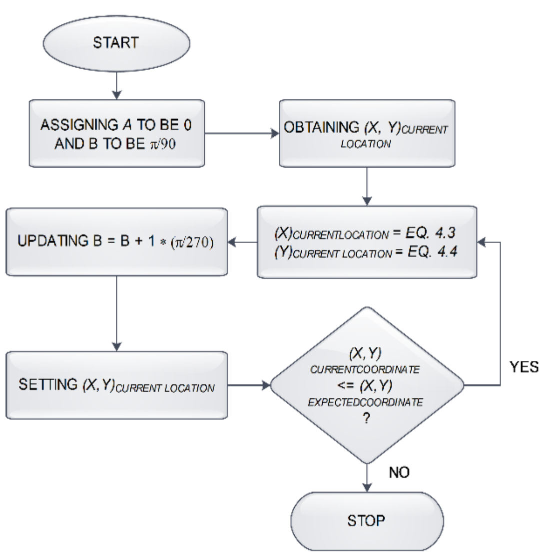


Figure 2 Flowchart for expanded circle

For quadcopters that has been applied is a flying robot that rely more on the calculation of equation that is mentioned below.

$$x = \left(a + \frac{b}{20}\right) \times math.\sin(b) \quad (1)$$

$$y = \left(a + \frac{b}{20}\right) \times math.\cos(b) \quad (2)$$

From these equations, the robot gets the current position and can perform expanding circle pattern as its basic pattern to do the exploration

The algorithm that is implemented in these quadcopter is mentioned in Algorithm 1.

Algorithm 1: Expanding Circle Pattern

assigning $a \leftarrow 0$
assigning $b \leftarrow \frac{\pi}{90}$
obtaining $(x, y)_{current\_location}$
assigning $x \leftarrow equation\ (1)$
assigning $y \leftarrow equation\ (2)$
assigning $z \leftarrow$ 2 or 3
calculating $b \leftarrow b + 1 \times \frac{\pi}{270}$
setting up $(x, y)_{current\_location}$

From this algorithm, it can be seen that for x and y coordinate, they depend on the equation (1) and (2). However, since two quadcopter will perform expanding circle pattern in different direction, one quadcopter will change the use of $\sin(b)$ and $\cos(b)$. It means that, when one quadcopter uses equation as mention above, another quadcopter will use $\sin(b)$ for y and $\cos(b)$ for x.

4.0 EXPERIMENTAL SETUP

In this section, a quadcopter has been designed using V-REP (Virtual Robot Experimentation Platform) by [17] that has become a model standard in robotics research and facilitate other researchers to conduct their works. The robot simulator V-REP, integrated development environment, is based on a distributed control architecture: each object/model can be individually controlled via an embedded script, a plugin, a ROS node, a remote API client, or a custom solution. This makes V-REP very versatile and ideal for multi-robot applications. Controllers can be written in C/C++, Python, Java, Lua, Matlab, Octave or Urbi.

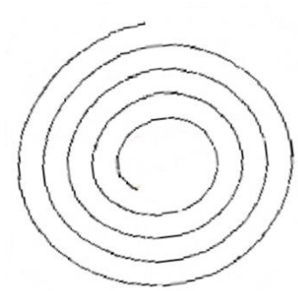


Figure 1 Expanding circle pattern

The use of quadcopter has some advantages. One of them is regarding the simplicity of its propulsion and navigation system that consists of four independent motors and propellers with fixed pitch. Each pair of opposite propellers rotates in the same direction to avoid yaw torque during roll and pitch movement. The whole system dynamics are controlled by thrust and torque triggered by every motor units.

The first experiment is dedicated only for one quadcopter to do the circle pattern. The quadcopter will simply move to perform expanding circle pattern where the pattern will be used as the basic model of pattern to perform exploration algorithm in searching mechanism later. The expanding circle pattern can be seen in Figure 2.

The basic idea of expanding circle pattern is to start the pattern from a fixed central point. Then the searching is based on the circumference of a circle. The radius of a circle is defined from central point and dependent on visibility. After completing one full circle, it will increase the radius by an amount that indicate an overlap between current circle and the previous circle.

Furthermore, for the improved experiment, it is conducted by using two quadcopter. These two quadcopter has different number of altitude. Two quadcopter has different direction to do the expanding circle pattern of their exploration pattern. It means that one quadcopter go right and another quadcopter will go reverse. The expanding circle pattern is shown in Figure 3. They will start the movement from different position.

5.0 RESULT AND DISCUSSION

The simulation development has taken a period of time where start from robot simple navigation system that can only move from one point to another point. Finally, the project reaches the objective which is the movement of two quadcopters that can implement expanding circle pattern to do the exploration activity. It can be seen in Figure 3 and 4.

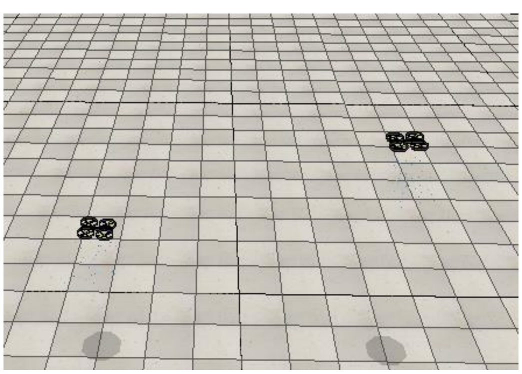


Figure 3 Two quadcopter perform expanding circle patter to discover certain area

In Figure 5, the quadcopter is viewed from vertical position that show that two quadcopter circle pattern is expanded from time to time. Figure 5 shows the area covered by single robot.

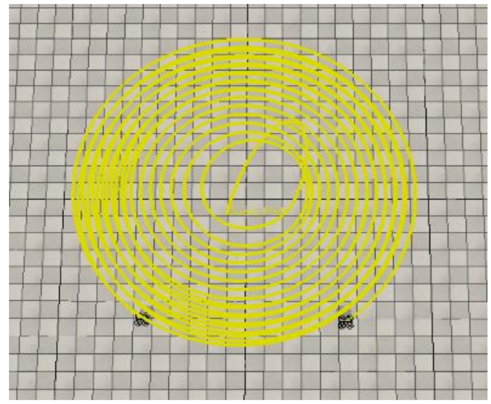


Figure 4 Two quadcopter perform expanding circle patter to discover certain area

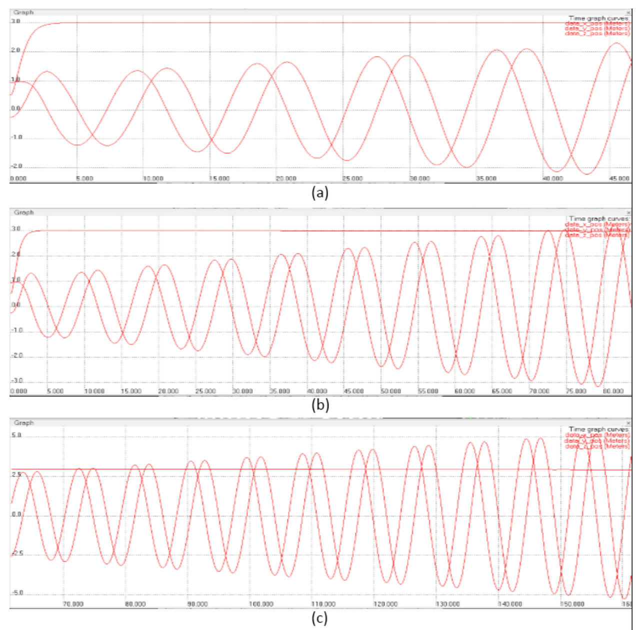


Figure 5 The graph for circle pattern

From those three graphs, they show that the quadcopter will extend its covered area as long as the time is increased. In other words, it shows that the area explored will be larger and larger as long as the quadcopter continue their exploration.

For example, in Figure 5(a), it shows that in the time 35.000 ms, the quadcopter can cover area in radius 2 meters. The radius will increase as the time is increased as well as shown in Figure 5(b). Here, after 70.000 ms, the quadcopter can cover area in radius 3 meters. It proves the circle is expanded by time to time. Furthermore, in Figure 5(c), after 350.000 ms, the radius is extended to 5 meters. Eventually, it shows that the expanding circle can be implemented for exploration so that the explored area can be larger from time to time.

Besides that, if the quadcopter begin its exploration in the centre of expected explored area, the quadcopter can cover the area more in term of it cardinal point direction as shown in Figure 6. It means that, the quadcopter will not only cover certain direction, whether it is north, east, south or west but all those four directions at once

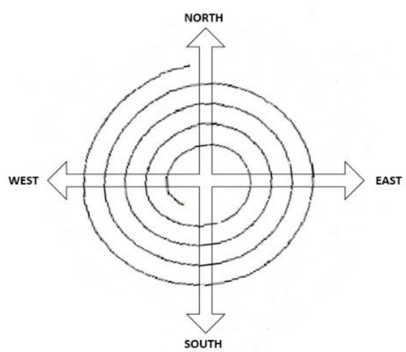


Figure 6 Cardinal Point

6.0 CONCLUSION

As the main idea of this paper, the expanding circle pattern takes a big role in exploration because it becomes the basic method for quadcopter to take path in their exploration.

It is clear that, the idea to implement expanding circle pattern to exploration activity can be proved as a better idea to cover a very large environment. It can be concluded that a quadcopter can cover area towards four cardinal points which is as a target of the exploration directly. For future work, the altitude of quadcopter can be observed more to identify the best altitude to do the exploration in a certain area.

Acknowledgement

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