Exploration of Unknown Map for Gas Searching and Picking Up Objects using Khepera Mobile Robots

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Abstract: In this paper, the integrated approach for searching, detecting the source of gas leakage and capturing object using Khepera III mobile robot is introduced. It was tested in natural grid environments as shown in experiments but it is usable in vast areas; e.g. houses and labs to pick up gas victims. Experiments are performed using a master Khepera robot equipped with a gas sensor and two slave robots equipped with grippers to take the best path to pick up the object. Moreover, this paper proposes an improvement of Albers exploration algorithm to reduce the time required to explore an unknown map with different polygon obstacles. The proposed approach aims at minimizing the overall exploration time, making it possible to localize gas source in an efficient way, as demonstrated in V-REP simulation as well as real world experiments. A comparison among both algorithms has shown the effectiveness of the proposed one, where the percentage of performance speedup is about 30% to 57% depending on the size of the map and number of obstacles.

1 INTRODUCTION

Nowadays, using robots instead of humans in risk operations is an interesting point in the field of robotics. Autonomous Robots are typically designed to perform search operations in buildings, mines, and caves, which are considered extremely challenging complex environments. One of the first such challenges is the exploration of the environment. Robotic exploration is an online problem for map building in which mobile robots use their onboard sensors to discover gradually the physical and layout structure of the initially unknown environment.

The Evaluation of the current experimental exploration methods is solely based on relative comparisons between the robots' performance in some test environments (Amigoni, 2008). Subsequently, it is hard to evaluate the room size is available for improving on-line exploration strategies. The Whole comparison between on-line exploration strategies and optimal off-line performance in test maps is needed. It can be done based on the competitive ratio. Mainly, the competitive ratio is P_a/P_o of the on-line algorithm A, where P_a is the performance of A in a test environment while P_o is the performance of the offline algorithm which has knowledge of the map (Ghosh and Klein, 2010). Lots of studies have been done in mapping and exploration; see for example, (Higashikawa and Katoh, 2013), (Herrmann et al., 2010), (Icking et al., 2010) and, (Doriya et al., 2015).

Recently, It received looking for olfactory targets with mobile robots a great interest because of its importance in the detection of a chemical leak, and search and rescue operations. Many studies have been done in this field in (Marjovi and Marques, 2011) and (Le Comte et al., 2012). In this paper, map exploration and gas source detection are the main topics.

In the following discussion, we focus on improving Albers exploration algorithm to explore unknown grid maps with obstacles for detecting gas leakage source. Then, take the optimal path to the target nodes (potential victims). The motivation of this work is to give an explanatory prototype of a robotic system that saves people from fires and bottlenecks resulting from gas leakage and the potential ignition of fires. Using a multi-robot system in risk operations instead of firefighters ensures the safety of their lives and helps them to perform harder tasks. Motion planning is implemented on two various levels: sensor based and model based. At the model level (Bender et al., 2002),

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planning depends on a priori knowledge of the environment. There is a need to search for free paths between certain start and goal states. The Sensor path planners deal with the unexpected items in the scene and usually, they are perfect for obstacle avoidance using robot sensors. Both models are employed in our work where a sensor based module is utilized by a master Khepera robot which is supplied with a gas sensor circuit, and a model based module is used by two slaves Khepera robots as shown in Section 4.

The paper is organized as follows. Section 1 is an introduction. Section 2 gives the related work. Albers algorithm is discussed in section 3. Section 4 describes the Khepera III robot and the types of used sensors. Our proposed framework and algorithm are also introduced. Section 5 shows the accuracy of our approach in both real world and simulation experiments. Section 6 concludes the paper.

2 RELATED WORK

Most of the research work on the single-robot exploration of new maps relied on grid map using sensor model. A Robot should construct a whole map using the shortest path as much as possible. This problem was studied previously by many researchers, e.g., (Betke et al., 1995), and (Rivest et al., 2015). The general problem of exploring a room without obstacles with a competitive ratio of examining places with obstacles was introduced by (Deng et al., 1998). For a simple polygon, (Hoffmann et al., 2001) achieved a constant competitive ratio of c= 26.55, while (Albers et al., 2002) showed that constant competitive factor for maps with obstacles does not exist (Fekete and Schmidt, 2010). For rectilinear polygons, (Hammar et al., 2006) showed that the traveled distance according to the Manhattan metric is c= 1.50 in the case of having a starting point on the boundary. The original Ray algorithm to explore grids with rectangular obstacles is proposed by (Betke et al., 1995). In contrast (Albers et al., 2002) proposed an algorithm for exploring grids with arbitrary obstacles. We improved Albers algorithm with an average competitive ratio of (c= 1.35), but there is no a constant competitive ratio.

A Wireless Sensor Network (WSN) of an olfaction mobile robot to localize the odor source was suggested by (Qi et al., 2015). (IŞILAK, 2010) Designed WSN to detect gas leakage and warns person with sound and vibration especially for people of Al-Zheimer disease who are more likely to forget to close the gas in the kitchen. WSN based on smart home for elder people to provide them with a safe living was developed by (Ransing and Rajput, 2015). Rescue operation in mines is risky so (Chakkath et al., 2012) proposed a prototype of a mobile robot with a gas sensor, temperature sensor, and camera which transmit the live video signal to monitor the status in a tunnel. (Kim et al., 2015) proposed a method to improve object identification and also complement sensor drawbacks of the infrared and radar sensor for imaging through smoke by firefighter robot.

3 BACKGROUND

Albers Algorithm

Albers algorithm (Albers et al., 2002) can be called Lower Ray Traversal Algorithm (LRT) to be easily distinguished from the newly proposed one. The algorithm assumed that the outer boundary of the grid is rectangular and that no obstacles touch the outer boundary. The LRT algorithm is summarized as:

1) The robot starts from point x_1 and moves along the exterior boundary of the scene clockwise until it reaches x_1 again. By this, the robot could know the dimension of the map and determine the exterior lower open segment. 2) Let S be the lower open segment of the exterior boundary. A *Lower Open Segment* of any obstacle O is a maximal sequence of consecutive horizontal edges on the boundary of O so that the interior of O is south of the robot. Fig. 1 shows the lower open segment in the bold lines of the grid map with arbitrary obstacles. 3) Start from node x_{i+1} on the open segment S to move up in vertical ray on the northern direction until hitting the exterior boundary. Then, go south till hitting the open segment and go one step east on the segment and radiate another Up-Ray in a recursive operation till hitting the exterior boundary or obstacle O at point X. 4) If the up ray hits an obstacle O, then go around the boundary of the obstacle in a clockwise manner, detect the open segment of O till it reaches X again Then take the shortest path to the first point on the segment and recursively do ray traversal to continue exploring. If the robot faces another obstacle at Y, repeat the same processes. It goes for any new obstacle till exploring the latest obstacle, then go back to explore the uncompleted open segment of previous constraints and so on till all the map is entirely scanned as shown in figure 2. The obstacle is planned thoroughly if all the nodes are explored.

A significant advantage of the ray algorithm is that it applies the *depth-first search* strategy (DFS) which traverses all edges and guarantees drawing a complete map. However, Albers algorithm has some drawbacks including the following: 1) The robot traverses the same vertical ray twice because it goes up and

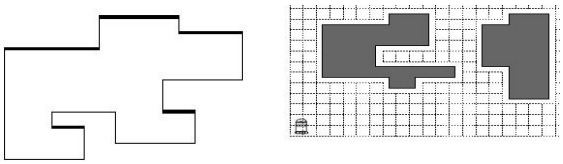


Figure 1: Left picture indicate open segment while right picture indicate grid map with arbitrary obstacles.

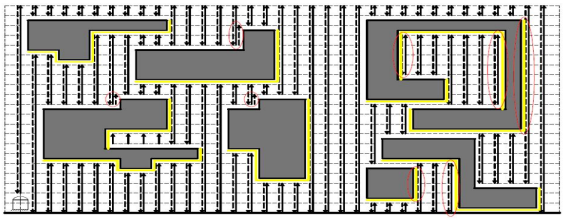


Figure 2: The Lower Ray Traversal Algorithm.

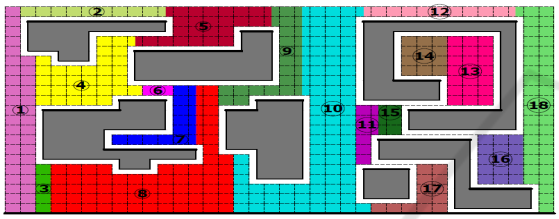


Figure 3: Exploring areas in non-ordered sections at 13, 14.

down on the same line to hit the lower open segment. Hence, this algorithm doubles the time of exploration. The newly proposed algorithm enhances this drawback; see section 4.2. 2) In case, the environment is occupied by multiple obstacles, the segment of the last obstacle is completely explored before the previous ones which mean that the robot would go back till the first obstacle is thoroughly explored which allows some horizontal edges to be traversed more than twice. This leads to exploring the map in a non-ordered way where region 13 explored before region 14 as shown in figure 3.

4 PROPOSED APPROACH

In this section, we introduce the methodology of an integrated approach to detect sources of gas leakage and capture objects using mobile robots. Beides, we propose an improvement to Albers algorithm.

4.1 Search and Picking Up Objects

Map exploration, gas source detection and picking up objects (potential gas leakage victim) using Khepera III robot are the main ideas in this paper. We developed a prototype integrated approach for the purpose of saving people from gas bottlenecks where the multi robot system consists of one master robot (R1) equipped with the gas sensor to search a rectangular grid map using our proposed zigzag ray traversal algorithm and detects the source of gas leakage. Then, It sends the environment map and the target point (object found beside gas source node) to two slave robots (R2,R3) by an intermediate computer with Ubuntu 12.04 operating system. Slave robots receive the map as well as the target point from the an intermediate computer through a Wireless compact flash card Wi-fi B/G: Ambicom WL5400G-CF module for network connection. They equipped with grippers to capture the object in the face to face.

In experiments in section 5, the two robots took the Dijkstra shortest path algorithm (E.W.Dijkstra, 1959) to the target point as shown in figure 8. R3 took the same path of R2 as it is the shortest one but it's path was increased with last three steps to face R2. R3 was delayed with an edge from R2 to avoid the collision between them. R2 reached before the object with a node and then checked arriving of R3 each time by using three front ultrasound sensor with threshold ($T \leq 55$) where T is the edge length in centimeter. R2 waited until R3 reach after the object with a node in a face to face position. Then, both of them began together to open the fingers of the gripper, fall to touch the ground, catch the object and go up.

4.2 Zigzag Ray Traversal Algorithm (Proposed Algorithm)

Let's call this algorithm lower upper ray traversal (LURT) which avoids the defects of the previous algorithm (LRT). The outline of the proposed LURT algorithm is explained in details in the following steps: 1) Start from any point on the corner of the map (e.g. x_i) and move along the exterior boundary of the scene until the robot reaches to x_i again. 2) Let S be the upper and lower segments of the outer boundary where An *Upper Segment* of any object O is a consecutive horizontal edges on the boundary of O so that the interior of O is north of the robot and *Lower Segment* is defined in Section 3. Fig. 4 shows the lower/upper segment in the bold blue/green lines respectively at the grid map with arbitrary obstacles. 3) Start from node x_{i+1} on the lower segment S to move up in a vertical ray in the northern direction until hitting the exterior boundary or an obstacle. When the ray hits the lower/upper exterior segment, it executes the zigzag process. If the ray hits the obstacle at point X_1, then it executes the obstacle boundary scan and explores segments. 4) At the end of exploring all obstacles, complete the exploration

Algorithm 1: Search and capture Object.

```
switch RobotsState do
    case Exploring do
        Master robot starts working;
        Apply zigzag ray traversal algorithm;
        Check gas odor at each node;
        if GasOdor == true then
            Mark this node as gas source node;
        if (ObjectBesideGasOdor == true)
          then
            Mark this node as a target point;
            Send the environment map and the
              target point to slave robots using
              an intermediary computer;
            Move the master robot to final
              corner on the boundary;
            Stop the master robot;
            RobotsState = TakingPath;
    case TakingPath do
        Slave robots start working;
        Apply Dijkstra algorithm;
        if (Robot1-ReachTarget == true) &
          (Robot2-ReachTarget == true) then
            Move gripper down;
            Catch Object, move gripper up;
end
```

by the zigzag traversal process.

The ***zigzag process*** can be outlined as follows: After radiating a ray to the north, move one step in the east and emit a ray in the reverse direction from the previous one (up/east/down).

The ***Obstacle boundary scan*** can be outlined as follows: 1) Move around the first obstacle clockwise until reaching X_1 again. 2) While moving, detect the up/down obstacle segment, store critical points (points of rotation) for each segment in a queue and mark them as visited. 3) After the boundary scan, go to the first point at the first segment of the obstacle to execute the exploration process.

The ***Segment exploration*** can be outlined as follows: 1) Start a zigzag ray traversal exploring from the first point at the first segment detected by the current obstacle. After exploring the first segment, move around the obstacle clockwise and go to the lowest point of the contiguous segment (lowest sum of x and y value of this point). 2) If any ray hits a new obstacle, then execute the boundary scan of the new obstacle, give priority to the new obstacle to be explored first, and execute the segment exploration. Recursively, do that for each new obstacle and then take the shortest path to the previous uncompleted obstacle to complete exploring. 3) If the ray radiated from any obstacle segment hits a visited point on a previous obstacle (which its exploring process has not been completed yet), then swap the priority of the exploration between the two obstacles to complete exploring the previous obstacle segments. 4) If the ray reaches the end-lock state, go in the reverse direction of the same line and execute a zigzag process. *End-lock*: If the right or the left side of the ends of the ray is an obstacle, it 's hard to move to move one step east in the zigzag process. Then, go in the reverse direction.

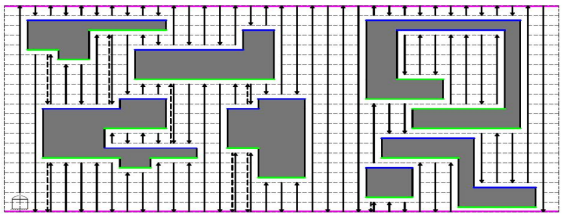


Figure 4: Zigzag Ray lines and lower/upper segment.

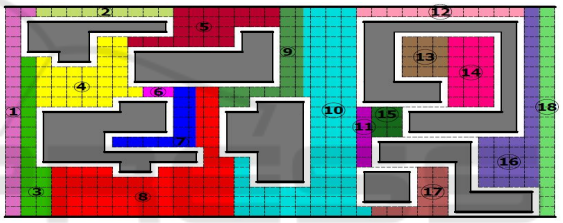


Figure 5: Exploring area in sequence at regions 13 and 14.

The following algorithm is the pusedo code of Zigzag Ray Traversal where symbols S1 is the left infrared sensor, S3 is the front sensor and S5 is the right sensor. Rdir is the robot direction.

The *main advantages* of the proposed algorithm: 1) Exploring the map totally in (half the duration achieved by the Albers algorithm + small factor σ) as will be showed in Section 5. σ factor is the same equal time of the exterior boundary travel, obstacles boundary travels and some vertical edge traverse of the two algorithms. To simply understand the difference between Albers algorithm and the proposed algorithm: assume the same map with obstacles as shown in Figures 2 and 4. The number of rays that passed the map is 187 in figure 2. In contrast, the number of rays is 102 in figure 4. Thus, the LURT algorithm explores the map in $0.545 + \sigma$ of the LRT. 2) The proposed algorithm scans the whole map in contiguous areas mostly as in figure 5. In contrast, Albers algorithm scans the same map in mostly non-contiguous areas as shown in figure 3. So, the main feature of the proposed algorithm is saving the time of traversing the map and saving the energy of the robot's battery in

Algorithm 2: Zigzag Ray Traversal.

```
while true do
    Execute Zigzag Ray Traversal Algorithm
end
switch state do
    case Idle do
        state=BoundaryScan
        Explore Forward;
    case BoundaryScan do
        if (x==0) & (y==0) then
            state=VerticalSweep
            SetMapDimension
            Explore Backward, Forward , Left
        else if (S3==false) & (S1==true) then
          Explore Forward
        else if (S3==true) then  Explore Right
    case ObsMap do
        if (x==ObsCell1.x)&(y==ObsCell1.y)
          then  state=BoundaryTravel
        Explore Forward
        else if (S3==false)&(S5==false) then
          Explore Right, Forward
        else if (S3==false) then
            if Rdir==Forward then
                Map(x+1,y)=obsIndex
            if Rdir==Backword then
                Map(x-1,y)=obsIndex
            if Rdir==Right then
                Map(x,y-1)=obsIndex
                Fill UpSegment Array
            if Rdir==Left then
                Map(x,y+1)=obsIndex
                Fill DownSegment Array
            Explore Forward
        else if (S3==true) then
            if Rdir==Forward then
                Map(x,y+1)=obsIndex
            if Rdir==Backword then
                Map(x,y-1)=obsIndex
            if Rdir==Right then
                Map(x+1,y)=obsIndex
                Fill UpSegment Array
            if Rdir==Left then
                Map(x-1,y)=obsIndex
                Fill DownSegment Array
            Explore Left
    case SegmentCheck do
        if (Rdir==Right)&(S5==true) then
            state=VerticalSweet; ExploreLeft;
        else if (Rdir==Right)&(S5==false)
          then
            state=BoundaryTravel;
             ExploreRight
        else Explore Nothing
end
```

Algorithm 3: Complete Zigzag Ray Traversal.

```
switch state do
    case BoundaryTravel do
        if (x == ObsCell1.x)&(y ==
          ObsCell1.y) then
            state=VerticalSweep
            Explore Left , Forward
        else if (S3==false)&(S5==false) then
            Explore Right, Forward
        else if (S3==false)&(Rdir==Right)
          then
            state=SegmentCheck
            Explore Forward
        else if S3==false then
            Explore Forward
        else if S3==true then
            Explore Left , Forward
    case VerticalSweep do
        if (S3==false) then  Explore Forward
        if (S3==true)&(Rdir==Forward) then
            if (y≤ vertCells-1) &
              Map(x,y+1)==0 then
                state=ObsMap
                obsIndex++
                Map(x,y+1)=obsIndex
                obsCell1.x= x
                obsCell1.y= y
                Explore Left , Forward
            else if (S5 ==
              true)&(Map(x,y+1)≥ 1) then
                Explore Backward
            else if (S5 == true)&(y
              ==vertCells) then
                state=Finish
            else Explore Right, Forward, Right
        if (S3==true)&(Rdir==Backword)
          then
            if (y≥ 1)&(Map(x,y-1)==0) then
                state=ObsMap
                obsIndex++
                Map(x,y-1)=obsIndex
                obsCell1.x=x
                obsCell1.y=y
                Explore Left , Forward
            else if (S1 == true)&(y ==0) then
                state=Finish;
            else if (S1==true)& Map(x,y-1)≥ 1
              then
                Explore Backward
            else
                state=BoundaryTravel
                Explore Left , Forward
    case Finish do
        Explore Halt
        Print explore all map
end
```

addition to usefulness for critical applications as rescue operations.

The *disadvantage* of the proposed algorithm is that it needs higher space storage than the LRT to store critical points for segments of any obstacle. The storage space is the number of queues needed to store critical points only. However, the storage cost is very small compared to the double rays of traversing a map in the real world.

4.3 Khepera Robot Platform

The Khepera III is a small mobile robot developed by K-Team, it has two wheels. The features of this robot could match the performance of much larger robots. The robot consists of 9 infrared sensors to detect an obstacle and five ultrasonic sensors to detect long-range objects. It also has two infrared sensors on its ground to follow the lines. Moreover, it allows for expansion using the Korebot II extension board for any external sensor, camera, or gripper as in figure 7 and 8. C/ C++ programming language are used to program the robot (Lambercy and Bureau, 2007).

Architecture of the Khepera III Robot: To reduce the compilation time of running the code on khepera III processor, the following parameter should be taken in consideration as explained in (XScale, 2002).

- *Processor:* Marvell PXA270 with XScale, *7 Stage* pipeline and32 KB instruction cache.
- *Dynamic Branch Prediction* to reduce the penalties of changing the flow of program execution.
- Supports *Write-back* or *write-through* caching.
- *Loop Unrolling:* loop with a fixed number of iterations may be faster if the loop is unrolled rather than trying to schedule prefetch instructions.
- SDRAM resources are typically: 4 memory banks, 1 page buffer per bank referencing a 4k address range and 4 transfer request buffers.
- *Out of Order Completion:* instructions may complete out of order because there are no data dependencies exist.
- *Use of Bypassing:* The pipeline makes extensive use of bypassing to minimize data hazards. It allows results forwarding from multiple sources, eliminating the need to stall the pipeline.The pipeline issues a single instruction per clock.

Calculate Real Speed in mm: In speed mode, the controller has a speed value of the wheels as input, and it controls the motor to keep this speed. The speed value is a division of a constant factor (16776960) by the time between encoder pulsations (Lambercy and Bureau, 2007).

$$MotorSpeed = \frac{16776960}{Timer5value} = \frac{\frac{Timer5value}{Postscaler}}{\frac{\frac{fosc}{4}}{Tmr5Prescaler}} \quad (1)$$

$$\begin{aligned} RealSpeed_{mm} &= ConversionFactor * MotorSpeed \\ RealSpeed_{mm} &= \frac{WheelCircumference}{Time * 2764} \end{aligned} \quad (2)$$

where ***ConversionFactor*** $= 6.9439 * 10^{-3}$, fosc = 20MHz, Tmr5Prescaler = 8, Postscaler = 4, WheelCircumference is 128.8mm and 2764 corresponds to the number of measures per a wheel revolution.

Odometry Distance and Orientation: The equations that govern the dynamics of the robot are as follows.

$$\begin{aligned} V &= \frac{V_R + V_L}{2} \\ W &= \frac{V_R - V_L}{WheelSpacing} \\ \theta &= \sum_{i=0}^{k} W_i \delta t \\ r &= \sum_{i=0}^{k} V_i \delta t [-\sin\theta a_x + \cos\theta a_y] \end{aligned} \quad (3)$$

Where V is the robot's velocity, V_R is the velocity of the right wheel, and V_L is the left wheel velocity. So the resultant velocity is the average of the velocities of the left and right wheels. W is the angular velocity and $WheelSpacing = 88.41mm$. θ is the odometer angle orientation, and r is the odometer distance, δt is the timestamp difference, the a_x is X direction, a_y is Y direction.

The Direction of the Robot is Relative to its Initial Position: Adjusting the robot's movement direction is relative to the initial position; we proposed this state diagram as shown in the following figure 6.

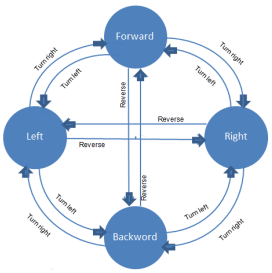


Figure 6: Robot state diagram to adjust movement direction.

Sensors used in the Experiments: Infrared sensors provide low range coverage, less than 0.5m in most cases, this is because the emitted energy is not concentrated. However, infrared sensors are cheap and reliable for many applications. For instance, they can be used successfully to detect obstacles that are close to the robot. The threshold of the two ground infrared proximity sensors to distinguish between white and black lines on the floor is 3000 while the threshold of the IR sensors to detect obstacle is greater than 65.

It is better to use the ultrasound sensor to detect obstacles in long distances. Each sonar sensor measurement provides information about the empty and occupied spaces in the cone in front of the sensor. The multiple measurements are integrated in a sonar sensor map, using a powerful tool that combines information from sensors in such a way to deal with errors and uncertainties in the data. We propose to take the best sonar reading as follows; take N measurements from each sensor, arrange them in ascending order, and then take the median value. This is probably the best reading.

Gas Sensor Circuit and Gripper: During exploration and navigation, the master robot is equipped with a gas sensor board developed manually by us as shown in figure 7. It can be used for detecting leakage gas equipment both in residential areas and industry.

The gas sensor module name is MQ-6. It is sensitive to LPG, iso-butane gas, propane, natural gas and town gas. It avoids the noise of alcohol, cooking fumes and, cigarette smoke. The sensor needs a resistor at the output to ground. Its value is ranging from 2kOhm to 47kOhm, the lower the value is, the less sensitive the sensor is. Also, the higher the value is, the less accurate, it is for higher concentrations of gas (Datasheet,). We choose 12kOhm as a suitable value in our designed circuit. The designed circuit in figure 7 is composed of the MQ-6 gas module. It has two leds; one of them is a power indicator, and the other one is an indicator of sensing the gas odor. Reading take digitally from bin number IO1 in KoreIOLE Extension Board.

Figure 7: Gas sensor circuit combined with khepera III.

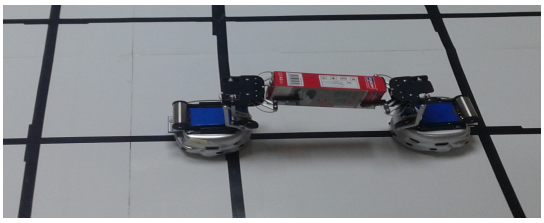


Figure 8: Two khepera III with grippers to capture object (potentional victim).

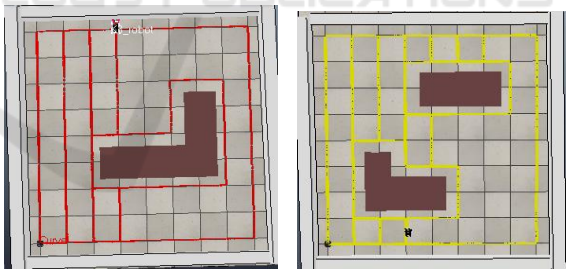
5 EXPERIMENTS

5.1 V-REP Simulation

V-REP is a very nice tool for fast prototyping and verification, remote monitoring and swift algorithm development. A V-REP plug-in was specially developed to allow an axiomatical and realistic Khepera robot simulation in (Rohmer et al., 2013).

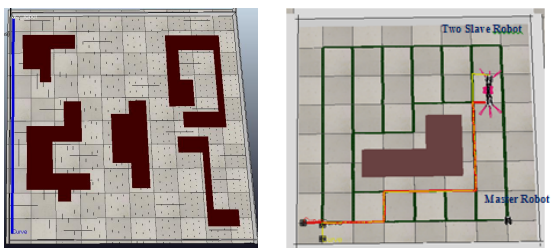
Table 1: Comparison between the proposed approach and Albers approaches in vrep simulation.

Test	Map Nodes	Obstacles	Albers in min	Zigzag in min	Speed Up
T1	9*9	1	22.5	14.5	35%.
T2	9*9	2	25	17.25	30%
T3	19*39	5	326.16	191.76	41.2%



(a) (b)

Figure 9: (a) Map with one obstacle in test-1, (b) Map with two obstacles in test-2.



(a) (b)

Figure 10: Left is a large map with five obstacles in test-3 and right shows the master robot track in green line, red and yellow lines are the tracks of the two slave robots in test-4.

The current section describes the experimental details, assumptions, and the obtained results tested by V-REP where the Lua programming language is used.

Use a Khepera robot to explore a map consisting of $n \times m$ nodes and N obstacles where n is the horizonal nodes, and m is vertical nodes and N is the number of barriers in the environment. Table 1 compares the result of Albers algorithm, and the Zigzag proposed algorithm. Test-1, Test-2, and Test-3 are shown in Figures 9 and 10 respectively.

Test-4: Use a master robot to explore a map that consists of 7×7 nodes with one obstacle and two slave robots to catch goal which demonstrates in Algorithm 1 as shown in figure 10.

5.2 Real World Experiment

Use a Khepera robot to explore a map consisting of $S \times R$ nodes and M obstacles where S is the horizonal nodes, and R is vertical nodes and M is the number of obstacles in the environment. Table 2 compares the result of Albers algorithm, and the Zigzag proposed algorithm. Test-1 and Test-2 are shown in Figure 11.

Table 2: Comparison between the proposed approach and Albers approaches in Real World.

Test	Map Nodes	Obsta-cles	Albers in min	Zigzag in min	Speed Up
T1	9*9	0	28	13	57%
T2	9*9	1	27	17	37%
T3	9*7	2	24	15	35%

(a) (b)

Figure 11: (a) Map with one obstacle in experiment-1 at real world, (b) Map with two obstacles in experiment-2.

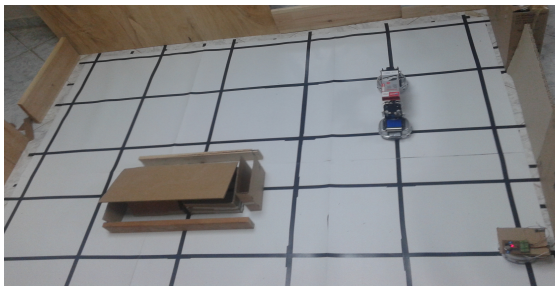


Figure 12: Master and slave robots in test-4 at real world.

Test-4: This experiment is a whole system where a master robot with the gas sensor is used in searching, and two slave robots with grippers are used for picking up the object as shown in figure 12.

6 CONCLUSIONS

This paper enhance Albers algorithm (LRT) by using proposed Zigzag Ray Traversal algorithm (LURT). The proposed (LURT) algorithm reduces the exploration time compared to the LRT. These algorithms are tested using the V-REP simulation and real world experiments. The percentage of performance speedup is about 30% to 57% depending on the size of the map and the number of obstacles as shown in figure 13, 14 . Also, this paper developped an itegrated approach for using Khepera robots in detecting gas leakage and capturing objects. All experiment as shown in vedio list link `https://www.youtube.com/playlist?list=PLzxdjgyt-2Qy6G-pAJ4zdXeK_V-OqDPM-` .

In future work, we will develop algorithms for multi-robot to explore large geometric maps without an intermediate computer in order to reduce the exploration time and enhance the overall performance. Dispensing an intermediate computer will make hard challenging in cooperation between robots and how much signals could transfer between them. Also, we will use laser range finder to detect far obstacles and objects easily and accurately.

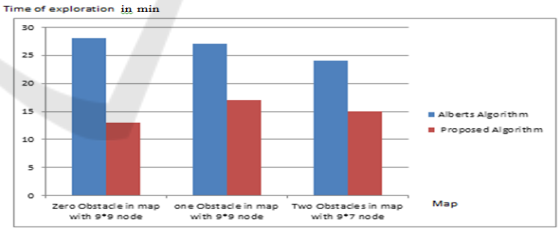


Figure 13: Comparing the results of Albers with our proposed algorithm in real world.

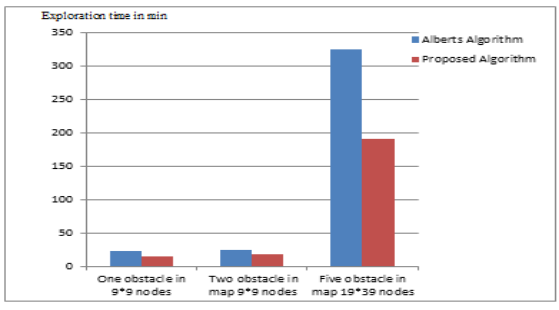


Figure 14: Comparing the results of Albers with our proposed algorithm in V−REP.

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