

Environmental Protection by Robots

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Abstract

In our Paper, we study the problem of how utilizing robots in an algorithm to protect the environment for n luminous robots when there is light provided with every robot. In this problem, we have to keep the robots visible to each other eventually without overlapping or colliding with each other while the robots moving to the environment circumference when they move to their final locations. The robots use Look, Compute, Move (LCM) modes. The robots are supposed the unobstructed vision in their solution meaning that three robots can see each other if they are on the same segment. They are also supposed rigid movements without adversary stopping them. The robots use lights to choose a color from the color set to indicate in which phase they are because except lights the robots are oblivious, and there is no information about each other, so they only can recognize the lights of each other to solve the problem. In our case, we use only two lights in the color set which is optimal since the problem requires at least two lights to get the optimal solution. In the luminous model of robots, the challenge is when the problem is solved using less lights without requiring the entire number of robots n . The algorithm we present requires $O(n)$ rounds as an execution time.

Keywords: *Protection; overlap-less; Luminous; Vision; Mobile*

1. Introduction

Robots are machines with some capabilities that are divided into two types static and mobile robots. Static robots cannot move from a place to another place. However, mobile robots are the robots that can move from a place to another place so that we used mobile robots in our work to facilitate the solution of our algorithm because of their flexibility in the motion. The robots are used in many aspects such as safety, protection, environmental protection, surveillance, good and data delivery, cleaning, medicine, technology, engineering, physics, nanotechnology, monitoring, and etc. These many important uses make a lot of sense in developing society. Our system consists of $n \geq 1$ robots operating in the Euclidean plane in two dimensions. We present an algorithm to solve the problem of utilizing the robots in the environmental protection. The robots follow the luminous model where every robot has a light [2,

5, 6, 7, 24]. Except the lights existing, the robots are oblivious [16] that are no memory usage, no identifiers, no markers, no control, no coordinate systems agreement, and no communication. The robots use the cycles of (LCM) where they look, compute, and move [14]. As soon as the robot is turned on, it looks about and takes a picture of it. The destination point is then calculated (computed). If its destination differs from its present location point, it ultimately moves to it (move). To tackle the challenge, every robot uses the same algorithm.

There are three modes of activation of robots. The first mode is fully-synchronous where every robot turns on and does its LCM cycles at the same time. The second one is semi-synchronous that is very close from the first mode, but some of robots turn on at the same time while the others are not.

Therefore, round is used instead of time in both first two modes. At the end, we have the last mode which is asynchronous mode where each robot is turned on in different time. It is unsure how long the look, compute, move cycles will delay, but the time is finished. The classical oblivious robots paradigm has been the subject of extensive research [1, 3, 4, 7]. In our case, the robots follow the luminous model where every robot has a light [2, 5, 6, 7, 24]. Except the lights existing, the robots are oblivious. Data transmission, intruder detection, exploration, coverage, and symmetry breaking are just a few of the numerous robot applications that use this paradigm [13]. Some of the works used the unobstructed visibility in their algorithm solutions. They supposed that the robots r_0 and r_2 can observe each other even if a third robot r_1 is present within the line segment connecting r_0 and r_2 since they assumed the point robots [4].

The recent work studies the problem of how protecting and monitoring an environment by using the robots when the vision of robots is unobstructed where the robots move on the boundaries or circumference of the environment from any arbitrary configuration or environment without overlapping with each other. Where there is a point shared between the robots at any time, then these robots are overlapped. As a result, we present an algorithm to get a solution to our problem. In our algorithm, the robots are moved to the boundaries of the environment to monitor and protect it without preventing the visibility of each other robot in the fully synchronous mode where n , the entire number of robots is not known by each robot. The problem is solved in luminous model using two lights in the color set black and gold.

According to our idea, there is no solution to the this problem of robots in the luminous model under the conditions that we used without any overlapping among robots. The solution of our algorithm uses two colors which is professional. While the algorithm is executed, the robots disagree regarding which axes to align. n is not award by the robots. $O(n)$ rounds are used by our

solution when the mode of robots' activation is fully-synchronous.

1.1 Related Work

Two models are available. The conventional model, which does not use lights, and the luminous type, which equips robots with visible lights [2, 5, 9, 11, 15, 20, 21, 23, 24, 25, 26, 27, 28]. The robots' luminous model allows them to change their lights by utilizing a color set that contains several hues. The light does not go out when the cycle is over. With the exception of the lighting model's light idea, the two models function similarly. When there is only one color in the set of colors, the classical model and the lights luminous model are comparable [15, 16]. When the issue is resolved, the lights model aims to determine how to reduce how many colors there are.

When addressing the issue, some earlier research looked at the classical robot model, while others looked at the robot lights model [11, 28]. The majority of earlier studies considered point robots once the issue was resolved [4, 8, 10, 12, 17, 18, 19, 22]. The related work to ours according to the idea of environmental protection by robots is by Alsaedi et al. [5] that creates a pattern of robots using luminous model that assists in protecting the environments.

2 Preliminaries

We have a collection of $n \geq 1$ obscure robots that work in the Euclidean plane: $R = \{r_1, r_2, r_3, \dots, r_n\}$. We suppose that the robots are not aware of n throughout the algorithm's execution. Every robot in the system has a unique coordinate system and is aware of its location in relation to that system. There may be disagreements among robots regarding the orientation of their coordinate systems, meaning that they do not have a similar understanding of direction. The robots are equipped with cameras to capture images, and their visibility is unrestricted.

We suppose that the robots r_0 and r_2 can observe each other even if a third robot r_1 is present within

the line segment connecting r_0 and r_2 since we assume the point robots [4].

An externally visible light that can take on any color from a static set C of colors is installed on each robot r_i . Every robot in R has the same set C . All robots visible to r at time t can observe the hue of robot r 's light at that moment. A set of n robots in $C \times R^2$ that specify the robots' colors and locations is called a configuration C . Let the configuration at time t be represented by C_t . The configuration C_t for robot r_i , or the set of robots $C \times R^2$ of the robots visible to r_i , is represented by $C_t(r_i)$. The robots use the cycles of (LCM) where they look, compute, and move [14]. As soon as the robot is turned on, it looks about and takes a picture of it. The destination point is then calculated (computed). If its destination differs from its present location point, it ultimately moves to it (move). To tackle the challenge, every robot uses the same algorithm. The mode of the activation of robots that we use is the first one which is fully-synchronous where every robot turns on and does its LCM cycles at the same time.

We say that the problem gets the solution if all the robots move to the circumference of the environment to monitor and protect the environment without overlapping with each other and changing their lights to gold color. These movements of robots can be done without enlarge the environment, i.e., in the same given area of the environment which is the challenge. The problem is solved without any assumptions such as chirality where every robot has to agree on the direction of robots and without requiring to determine the entire number of robots which is n in our case.

3 Algorithm

In this section, we present our algorithm that gets the solution of the problem of environmental protection by robots. we have a system of $n \geq 1$ of luminous robots that follow rigid movements in the fully-synchronous mode. Our solution requires two colors while solving this above problem $C = \{\text{black, gold}\}$. The black robot represents the robot in its initial instance or any other middle

instance. However, the gold robot represents the robot in its final instance which is in the circumference of the environment.

We have the following environment as an example; see Figure 1. Initially, all robots have black light.

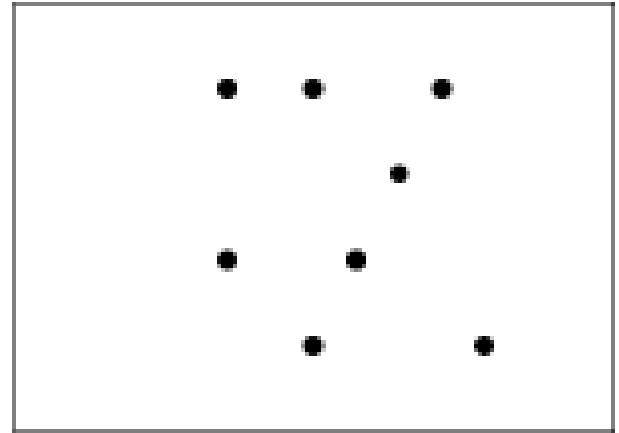


Figure 1: An example of an initial environment.

Each robot in the initial environment starts to move to be in the boundaries of this current environment. First of all, each robot determines the eligible edges that can move through without overlapping with other robots. Then, the robot chooses the closest eligible edge from the collection of its eligible edges. It checks that it will not overlap with other robot, i.e., it will not share a point with other robot in its way while moving to its final location on the closest eligible edge of the circumference of the given environment. It moves straightly to its final location if there is no other robot in its way. Since the robot has a camera with 360 degree of visibility, so it can observe if there is a robot in its way until getting its final location. If there is a robot in its way, so it can move one unit to the left or right according to the space available in its eligible edge, then it moves straightly to its final location on the edge. If there is no space on that closest eligible edge, then it chooses the second closest eligible edge from the collection of its eligible edges ensuring that no overlapping among robots. The robot has a light with black color in the initial instance until getting its final location. However, it turns on its light to gold color when it reaches its final location on the circumference of

the environment. The initial and final environments have the same area. When each robot has a light with gold color, then the problem is solved since each robot can observe its light and other robots' lights. Therefore, each robot can determine when the problem is solved by observing each robot's light with gold color in the circumference of the given environment. Figures 2, 3, 4, and 5 explain the robots movement to the circumference of the given environment with changing their lights to gold.

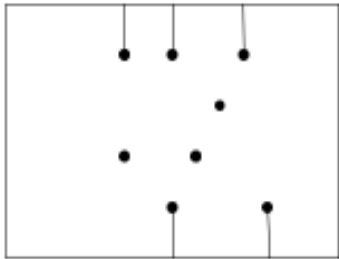


Figure 2: Step one of robots movement.

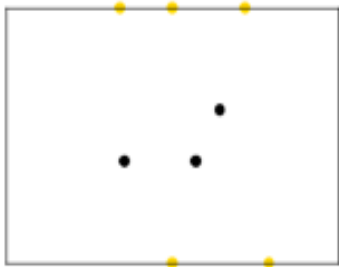


Figure 3: Step two of robots movement: the robots on the circumference of the environment set their lights to gold.

4 Analysis

In this section, we analyze our algorithm. We prove that our algorithm solves the problem of protecting the environment by robots in a linear time complexity without overlapping. Two colors are used.

We start to prove the solution of our algorithm.

Lemma 1. We have any initial environment C_0 ; there is no overlapping of robots occurs until all robots are on the circumference of the environment, meaning that no robots inside the environment.

Proof. Any robot r_i inside the initial environment with light black does not overlap with any other internal robot because the move of robot r_i is perpendicular to the closest edge, and there is enough space on the edge for the robot to move through it because the robots are points. The robots moving through different edges of the given environment do not overlap since those robots are the closest robots to those edges.

We then prove how each robot r_i chose the closest eligible edge is able to move to the circumference of the given environment.

Lemma 2. There exists a round such that the robots inside the given environment that are closest to their eligible edges are able to move on the boundaries of the given environment changing their lights to gold. Proof. By Lemma 1, the robot r_i does not overlap with other inside robots while it tries to move to its closest edge of our given environment. By the same Lemma 1, there is no overlapping for robot r_i while it moves to the closest eligible edge. Since the movements are rigid, r_i reaches its computed location on the edge once it moves and changes its color to gold. In the following statement, we have to count the number of lights or colors required by our solution. Lemma 3. Our algorithm is completed requiring two colors.

Proof. By Lemma 1 and Lemma 2, each robot requires at most two colors which are black and gold, and the lemma follows.

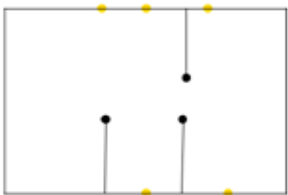


Figure 4: Step three of robots movement.



Figure 5: All robots are on the circumference of the given environment with gold lights.

Lemma 4. When all n robots move to the circumference of the given environment, $O(n)$ rounds are spent until getting the solution of our algorithm.

Proof. Since in the worst case, we have all robots inside the given environment. Each robot moves perpendicularly to its closest eligible edge needing only one round. If the robot senses that it may overlap with other robots, it moves one unit to the left or right according to the available space on its way by its visibility before its movement to its final location on the boundaries of the given environment. This requires another round. Therefore, in the worst case each robot requires at most two rounds unit moving to its final location. This gives as a result $O(n)$ is the entire time required by our solution. Ultimately, we conclude with the following theorem. Theorem 5. In a fully-synchronous mode, our approach uses two colors to solve the Environmental Protection by Robots issue in $O(n)$ rounds without overlapping.

5 Conclusion

We presented an algorithm that got the solution for the problem of Environmental Protection by Robots for a system of n robots in the luminous model without overlapping. We used the fully-synchronous mode and rigid movements in our solution. $O(n)$ rounds are required by our algorithm to get the solution of the problem. In this problem, we used two lights which is professional and optimal solution since any problem in this model needs at least two lights to be solved [2].

For future work, it is motivating to extend and develop our algorithm to get the solution of the problem in the traditional model without lights and using other modes of activation which are semi-synchronous mode and asynchronous mode.

References

1. Rusul J Alsaedi. Gathering problem for fat mobile robots using memory. *International Journal of Science and Research*, 2024.
2. Rusul J Alsaedi, Joachim Gudmundsson, and Andr e van Renssen. The mutual visibility problem for fat robots. In *Algorithms and Data Structures Symposium*, pages 15–28. Springer, 2023.
3. Rusul J Alsaedi, Joachim Gudmundsson, and Andr e van Renssen. Pattern formation for fat robots with memory. *arXiv preprint arXiv:2309.14649*, 2023.
4. Rusul J Alsaedi, Joachim Gudmundsson, and Andr e van Renssen. Shortest paths of mutually visible robots. *arXiv preprint arXiv:2309.16901*, 2023.
5. Rusul J Alsaedi, Joachim Gudmundsson, and Andr e van Renssen. Pattern formation for fat robots with lights. *Computational Geometry*, page 102161, 2024.
6. Rusul Jabbar Abbas Alsaedi. On the mutual visibility of fat mobile robots. Kent State University, 2016.
7. Rusul Jabbar Abbas Alsaedi. *Visibility and Pattern Formation Problems in Robotics*. The University of Sydney, 2024.
8. Kaustav Bose, Ranendu Adhikary, Manash Kumar Kundu, Archak Das, and Buddhadeb Sau. Distributed pattern formation by autonomous robot swarm. In *23rd International Conference on Distributed Computing and Networking (ICDCN)*, pages 242–243, 2022.
9. Kaustav Bose, Ranendu Adhikary, Manash Kumar Kundu, and Buddhadeb Sau. Arbitrary pattern formation by opaque fat robots with lights. In *Conference on Algorithms and Discrete Applied Mathematics (CALDAM)*, volume 12016 of *Lecture Notes in Computer Science*, pages 347–359, 2020.
10. Kaustav Bose, Archak Das, and Buddhadeb Sau. Pattern formation by robots with inaccurate movements. In *25th International Conference on Principles of Distributed Systems (OPODIS)*, volume 217 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pages 10:1–10:20, 2021.
11. Kaustav Bose, Manash Kumar Kundu, Ranendu Adhikary, and Buddhadeb Sau. Arbitrary pattern formation by

- asynchronous opaque robots with lights. *Theoretical Computer Science*, 849:138–158, 2021.
12. Sruti Gan Chaudhuri, Swapnil Ghike, Shrainik Jain, and Krishnendu Mukhopadhyaya. Pattern formation for asynchronous robots without agreement in chirality. *arXiv preprint arXiv:1403.2625*, 2014.
 13. Mark Cieliebak, Paola Flocchini, Giuseppe Prencipe, and Nicola Santoro. Distributed computing by mobile robots: Gathering. *SIAM Journal on Computing*, 41(4):829–879, 2012.
 14. Shantanu Das, Paola Flocchini, Giuseppe Prencipe, Nicola Santoro, and Masafumi Yamashita. Autonomous mobile robots with lights. *Theoretical Computer Science*, 609:171–184, 2016.
 15. Giuseppe Antonio Di Luna, Paola Flocchini, S Gan Chaudhuri, Federico Poloni, Nicola Santoro, and Giovanni Viglietta. Mutual visibility by luminous robots without collisions. *Information and Computation*, 254:392–418, 2017.
 16. Paola Flocchini, Giuseppe Prencipe, and Nicola Santoro. Distributed Computing by Oblivious Mobile Robots. *Synthesis Lectures on Distributed Computing Theory (SLDCT)*. Springer Cham, 2012.
 17. Nao Fujinaga, Yukiko Yamauchi, Hirotaka Ono, Shuji Kijima, and Masafumi Yamashita. Pattern formation by oblivious asynchronous mobile robots. *SIAM Journal on Computing*, 44(3):740–785, 2015.
 18. Satakshi Ghosh, Pritam Goswami, Avisek Sharma, and Buddhadeb Sau. Move and time optimal arbitrary pattern formation by asynchronous robots on infinite grid. *International Journal of Parallel, Emergent and Distributed Systems*, 38(1), 2023.
 19. Manash Kumar Kundu, Pritam Goswami, Satakshi Ghosh, and Buddhadeb Sau. Arbitrary pattern formation by opaque fat robots on infinite grid. *International Journal of Parallel, Emergent and Distributed Systems*, 37(5):542–570, 2022.
 20. Giuseppe Antonio Di Luna, Paola Flocchini, Sruti Gan Chaudhuri, Nicola Santoro, and Giovanni Viglietta. Robots with lights: Overcoming obstructed visibility without colliding. In *16th International Symposium on Stabilization, Safety, and Security of Distributed Systems (SSS)*, volume 8756 of *Lecture Notes in Computer Science*, pages 150–164, 2014.
 21. Giuseppe Antonio Di Luna, Paola Flocchini, Federico Poloni, Nicola Santoro, and Giovanni Viglietta. The mutual visibility problem for oblivious robots. In *26th Canadian Conference on Computational Geometry (CCCG)*, 2014.
 22. Debasish Pattanayak, Klaus-Tycho Foerster, Partha Sarathi Mandal, and Stefan Schmid. Conic formation in presence of faulty robots. In *16th International Symposium on Algorithms and Experiments for Wireless Sensor Networks (ALGOSENSORS)*, volume 12503 of *Lecture Notes in Computer Science*, pages 170–185, 2020.
 23. David Peleg. Distributed coordination algorithms for mobile robot swarms: New directions and challenges. In *7th International Workshop on Distributed Computing (IWDC)*, volume 3741 of *Lecture Notes in Computer Science*, pages 1–12, 2005.
 24. Gokarna Sharma, Rusul Alsaedi, Costas Busch, and Supratik Mukhopadhyay. The complete visibility problem for fat robots with lights. In *Proceedings of the 19th International Conference on Distributed Computing and Networking*, pages 1–4, 2018.
 25. Gokarna Sharma, Costas Busch, and Supratik Mukhopadhyay. Bounds on mutual visibility algorithms. In *27th Canadian Conference on Computational Geometry (CCCG)*, pages 268–274, 2015.

26. Gokarna Sharma, Costas Busch, and Supratik Mukhopadhyay. Mutual visibility with an optimal number of colors. In 11th International Symposium on Algorithms and Experiments for Wireless Sensor Networks (ALGOSENSORS), volume 9536 of Lecture Notes in Computer Science, pages 196–210, 2015.
27. Ramachandran Vaidyanathan, Costas Busch, Jerry L. Trahan, Gokarna Sharma, and Suresh Rai. Logarithmic-time complete visibility for robots with lights. In 29th IEEE International Parallel and Distributed Processing Symposium (IPDPS), pages 375–384, 2015.
28. Ramachandran Vaidyanathan, Gokarna Sharma, and Jerry Trahan. On fast pattern formation by autonomous robots. *Information and Computation*, 285:104699, 2022.