Forming Conic Patterns with Faulty Robots*

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Extended Abstract

Self-organization have fascinated researchers for many years. It is very common to find self-organizing structure in the physical world, be it a set of molecules forming a crystal, a set of enzymes producing a complex protein, or a swarm of insects. The decentralized nature of these self-organizing system make them robust with respect to faults. Extending this nature to artificial objects, we consider this self-organizing capability in the context of *robotics*. Pattern formation [6, 7] for robots have been extensively studied for non-faulty robots exploring the characterization of patterns [10] with limited visibility [5, 12]. Gathering [3], a special case of pattern formation, have been considered in presence of faults [1, 9]. Further special cases of pattern formation such as plane formation [11], uniform circle formation [4] has also been considered in the literature as well. In particular, we explore the formation of specific patterns by a set of robots in presence of faulty robot. Unlike gathering with faults, we want to have the faulty robots as a part of the pattern. This is challenging since the robots are unable to differentiate between a faulty and non-faulty robot.

The robot model considered is the following. Each robot is a dimensionless point robot. The robots are homogeneous: they execute the same deterministic algorithm, are indistinguishable and anonymous (no identifiers), oblivious (no persistent memories), and silent (no communication). The robots do not share a common coordinate system and observe others in their own *local coordinate system*. The robots have unlimited visibility, and the determined locations of other robots are precise. Each robot follows the *look-compute-move* cycle. A robot obtains a snapshot of relative positions of other robots with respect to its position in the *look* state. Based on the snapshot of other robot positions, it decides a destination in the *compute* state. In the *move* state, it moves to the destination and reaches the destination in the same round. This is known as *rigid* robot movement. The scheduler, which activates the robots, follows a fully-synchronous ($FSYNC$) model, i.e., all the robots look at the same time and finish movement in the same round. We consider that the robots are susceptible to crash-faults, i.e., they stop moving after the crash and never recover. Moreover, the number of f faulty robots is known beforehand, and as such, the robots know which types of pattern to form. In particular, we assume that the following four initial conditions hold:

- All f faulty robots have already crashed initially.
- All initial configurations are asymmetric.[1]
- All robots occupy distinct positions initially.[2]
- The faulty robots form a convex polygon.

*A short abstract of the paper "Conic formation in presence of faulty robots" [8]

[1] This assumption allows us to have a unique ordering of the robots [2].

[2] As any set of non-faulty robots that share a position will always perform the same actions from then on and be indistinguishable from each other.

Under these conditions, we try to form patterns specific to the number of faults f. The target patterns are point, line, circle and parabola for $f = 1, 2, 3$ and 4, respectively. For $f = 5$, the target patterns are parabola, hyperbola and ellipse. This stems for the fact that five points uniquely determine a conic, thus we consider all the patterns correspondingly. First, we show a lower bound of two rounds and a lower bound of at least $2f + 1$ robots for $f > 1$. The requirement of two round is to determine the faulty robots in the first round by virtue of its position and inability to move. Thus in the second round, the robots determine the pattern they should move to that includes the faulty robots. In case of the number of robots, a majority is needed to determine the target pattern among multiple patterns that have common robot positions.

We design the pattern formation algorithm to form the target pattern in one round assuming some of the robots to be faulty. Since the robots are oblivious and do not possess any method to distinctly identify faulty from non-faulty robots, the algorithm may not succeed in one round. We design the movement of the robots such that if a robot moves, it occupies a uniform position on the target pattern determined based on the configuration of the robots in that round. On the second round, the robots consider the robots at non-uniform positions to be faulty and determine a pattern that consists of the robots located at those non-uniform positions. After movement is finished in the second round, all the robot positions satisfy the same conic pattern and the algorithm terminates.

This work is the first to consider pattern formation with faults. In this work, some of the assumptions are strict with respect to the models of other pattern formation problems. Further relaxations on the assumptions of synchrony, role of asymmetry, knowledge of the number of faults can be explored as a future work.

References

1. Agmon, N., Peleg, D.: Fault-tolerant gathering algorithms for autonomous mobile robots. SIAM J. Comput. **36**(1), 56–82 (2006)
2. Chaudhuri, S.G., Mukhopadhyaya, K.: Leader election and gathering for asynchronous fat robots without common chirality. J. Discrete Algorithms **33**, 171–192 (2015)
3. Cieliebak, M., Flocchini, P., Prencipe, G., Santoro, N.: Distributed computing by mobile robots: Gathering. SIAM J. Comput. **41**(4), 829–879 (2012)
4. Flocchini, P., Prencipe, G., Santoro, N., Viglietta, G.: Distributed computing by mobile robots: uniform circle formation. Distributed Comput. **30**(6), 413–457 (2017)
5. Flocchini, P., Prencipe, G., Santoro, N., Widmayer, P.: Gathering of asynchronous robots with limited visibility. Theor. Comput. Sci. **337**(1-3), 147–168 (2005)
6. Flocchini, P., Prencipe, G., Santoro, N., Widmayer, P.: Arbitrary pattern formation by asynchronous, anonymous, oblivious robots. Theor. Comput. Sci. **407**(1-3), 412–447 (2008)
7. Fujinaga, N., Yamauchi, Y., Ono, H., Kijima, S., Yamashita, M.: Pattern formation by oblivious asynchronous mobile robots. SIAM J. Comput. **44**(3), 740–785 (2015)
8. Pattanayak, D., Foerster, K., Mandal, P.S., Schmid, S.: Conic formation in presence of faulty robots. CoRR **abs/2003.01914** (2020), `https://arxiv.org/abs/2003.01914`
9. Pattanayak, D., Mondal, K., Ramesh, H., Mandal, P.S.: Gathering of mobile robots with weak multiplicity detection in presence of crash-faults. J. Parallel Distrib. Comput. **123**, 145–155 (2019)
10. Yamashita, M., Suzuki, I.: Characterizing geometric patterns formable by oblivious anonymous mobile robots. Theor. Comput. Sci. **411**(26-28), 2433–2453 (2010)
11. Yamauchi, Y., Uehara, T., Kijima, S., Yamashita, M.: Plane formation by synchronous mobile robots in the three-dimensional euclidean space. J. ACM **64**(3), 16:1–16:43 (2017)
12. Yamauchi, Y., Yamashita, M.: Pattern formation by mobile robots with limited visibility. In: Structural Information and Communication Complexity - 20th International Colloquium, SIROCCO 2013, Ischia, Italy, July 1-3, 2013, Revised Selected Papers. pp. 201–212 (2013)