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科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Automatic Verification of Distributed Mobile Robot Algorithms

研究課題名（英文）Automatic Verification of Distributed Mobile Robot Algorithms

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交付決定額（研究期間全体）：（直接経費）　　1,400,000円

研究成果の概要（和文）：二年目も、ツールの開発を行い、このツールによってロボットのgathering問題のアルゴリズムの正しさの確認ができました。Workshop on Distributed Robotics Swarms (WDRS'15)で発表し、さらにAdHoc-Now '16の国際会議に採択され、発表する予定です。

研究成果の概要（英文）：In this second year of funding, we continued the development of the tool and obtained some new results.
(1) We had a paper accepted in AdHoc-Now'16 (to be published in July), which is an extension of our previous work: With the help of our verification tool, we could design and check new algorithms to solve the gathering problem in rings with four robots. More precisely, we studied the class of configurations SP4 which is the single class left open in this context. Same results were also presented in the Workshop on Distributed Robotic Swarms (WDRS'15).
(2) While being on a totally different topic, namely Game Theory, we would like to mention another accepted paper (in CG'16, to be published in July). Indeed to obtain this result, we used techniques similar to the ones we introduced in our verification tool. Hence our Kakenhi funding indirectly contributed to that paper. We developed a tool that compute Nash Equilibrium (NE) and used it to find NE of the famous Mastermind game.

研究分野：Distributed Computing

キーワード：Algorithm　Distributed Computing　Robot　Verification

１．研究開始当初の背景

This research project belongs to the field of theoretical distributed mobile robot computing. In this area, researchers study how multiple mobile robots can cooperate together, without any central organization, in order to solve a given task. Typical studied problems consist in gathering (e.g. [2,3,4]), exploration (e.g. [5,6]), and pattern formation (e.g. [2,7,8]).

This area of research started around 15 years ago [2,7] with the introduction of the first computational models for distributed robot computing. Later, it gained popularity and is now a very active field of research. The recent survey [1], published last year, includes more than 130 references (international conferences/journals). Most of these papers come from the last 10 years.

Nowadays, the research community is geographically widely spread; there are researchers from all around the world working on these subjects; in Japan (Kyushu University, Nagoya Institute of Technology, Osaka University, …), in Europe (France, Italy, Spain, …), and in America (Canada and USA).

Personally, I started to work on these topics during my PhD, a few years ago (references [9,10]), and I focused more on this research area during my post-doctoral studies at JAIST (Japan Advanced Institute of Science and Technology) as a JSPS fellow. Near the end of my fellowship, I realized that we need such a verification tool and it is the reason why I now propose this research project.

In our community, papers typically study a specific problem under a given model. Usually, authors look for the required assumptions that make the problem solvable or unsolvable, and then, propose algorithms solving the problem, including proofs and/or experimentations to assess their correctness.

However, some of the proposed algorithms appear to be incorrect, at least for some specific cases. For example, the paper [6] contains two errors that were not detected prior to publication. The errors come from both the intrinsic complexity of these algorithms and the difficulty of analyzing distributed algorithms. We believe that many of these errors could be detected using an automatic verification software.

Bibliography (title&authors only):

[1] *Distributed Computing by Oblivious Mobile Robots*, Paola Flocchini, Giuseppe Prencipe, Nicola Santoro.
[2] *Distributed Anonymous Mobile Robots*, Ichiro Suzuki, Masafumi Yamashita.
[3] *Taking advantage of symmetries: Gathering of many asynchronous oblivious robots on a ring*, Ralf Klasing, Adrian Kosowski, Alfredo Navarra.
[4] *Gathering of Robots on Anonymous Grids without Multiplicity Detection*, Gianlorenzo D'Angelo, Gabriele Di Stefano, Ralf Klasing, Alfredo Navarra.
[5] *Computing Without Communicating: Ring Exploration by Asynchronous Oblivious Robots*, Paola Flocchini, David Ilcinkas, Andrzej Pelc, Nicola Santoro.
[6] *Exclusive Perpetual Ring Exploration without Chirality*, Lélia Blin, Alessia Milani, Maria Potop-Butucaru, Sébastien Tixeuil.
[7] *Hard Tasks for Weak Robots: The Role of Common Knowledge in Pattern Formation by Autonomous Mobile Robots*, Paola Flocchini, Giuseppe Prencipe, Nicola Santoro, Peter Widmayer.
[8] *Distributed Anonymous Mobile Robots: Formation of Geometric Patterns*, Ichiro Suzuki, Masafumi Yamashita.
[9] *Anonymous graph exploration without collision by mobile robots*, Roberto Baldoni, François Bonnet, Alessia Milani, Michel Raynal.
[10] *On the Solvability of Anonymous Partial Grids Exploration by Mobile Robots*, Roberto Baldoni, François Bonnet, Alessia Milani, Michel Raynal.

２．研究の目的

The main goal of this research is therefore to propose a tool to automatize the verification of distributed mobile robots algorithms. We would like to point out that designing and developing such a tool does not consist only in a simple engineering task. Due to the nature of robots algorithms, we need to investigate new modeling/verification techniques and it is where the interesting research lies. The problems to investigate include, but not limited to, the followings:

- How to include the notion of mobility in the verification process?
- How to include the multiple possible scheduling of independent robots?
- How to take in consideration the potential failures of robots?

３．研究の方法

This project targets the development of a verification tool for distributed mobile robot algorithms. The research plan and method can briefly be summarized in three points:

- Review existing literature to determine the features which have to be included in our tool,
- Develop, test, and use the tool to obtain new results (three tasks in parallel),
- Disseminate and promote the tool among the research community. We expect to receive relevant comments in order to improve the tool such that it becomes widely used.

The project is divided into five tasks that could be summarized as follow:

Task 1: Study existing literature on distributed mobile robots computing in order to extract all features that need to be included in our verification tool.

Task 2: Develop a working prototype with only few features to illustrate the necessity of such tool.

Task 3: Include more features.

Task 4: Investigate new problems assisted by the tool.

Task 5: Disseminate our tool to the community.

４．研究成果

For FY2014:

We could include some new functionalities in our verification tool, such as (1) taking into account the possibility of robots to create tower (multiple robots on the same location), (2) allowing the activations of multiple robots in the same round, (3) including the gathering problem in addition to the exploration problem that we initially considered. Following these improvements, as expected in the plan, we could obtain some interesting results from the first year. Such progress was made possible due to meetings with other researchers while attending conferences (especially DISC'14) and during a visiting trip to LIP6 (University of Paris 6) in early 2015.

In particular, we had a paper published in WSSR-SRDS'14. Our method permits to discover new protocols solving the exploration problem, and to assess specific optimization criteria (such as individual coverage, visits frequency, etc.) that are met by those protocols.

For FY2015:

In this second year of funding, we continued the development of the tool and obtained some new results.

In particular, we had a paper accepted in AdHoc-Now'16 (to be published in July), which is an extension of our previous work: With the help of our verification tool, we could design and check new algorithms to solve the gathering problem in rings with four robots. More precisely, we studied the class of configurations SP4 which is the single class left open in this context.

For FY2016 (future work):

We did not release yet our tool to the community. In the coming year, we plan to finish it and finally make our toll available online.

５．主な発表論文等

（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計６件）

(1) François Bonnet, Maria Potop-Butucaru, Sébastien Tixeuil, Asynchronous Gathering in Rings with 4 Robots, In Proceedings of the 14th International Conference on Ad-hoc, Mobile, and Wireless Networks, AdHoc-Now16, 14pages, 2016. (accepted, not yet published)
DOI: not yet available.

(2) François Bonnet, Simon Viennot, Nash Equilibrium in Mastermind, In Proceedings of the 8th International Conference on Computers and Games, refereed, CG16, 12pages, 2016. (accepted, not yet published)
DOI: not yet available.

(3) François Bonnet, Xavier Défago, Thanh Dang Nguyen, Maria Potop-Butucaru, *Tight bound on mobile Byzantine Agreement*, In Theoretical Computer Science, refereed, Volume 609, Part 2, p.361-373, 2016.
DOI: 10.1016/j.tcs.2015.10.019

(4) François Bonnet, Xavier Défago, Franck Petit, Maria Potop-Butucaru, Sébastien Tixeuil, *Discovering and Assessing Fine-Grained Metrics in Robot Networks Protocols*, In 2014 IEEE 33rd International

Symposium on Reliable Distributed Systems Workshops, refereed, SRDSW14, p.50-59, 2014.
DOI: 10.1109/SRDSW.2014.34

(5) François Bonnet, Xavier Défago, Thanh Dang Nguyen, Maria Potop-Butucaru, *Tight Bound on Mobile Byzantine Agreement*, In Distributed Computing, 28th International Symposium, refereed, DISC14, p.76-90, 2014.
DOI: 10.1007/978-3-662-45174-8_6

(6) Thanh Dang Nguyen, François Bonnet, Xavier Défago, *Mitigating the Spread of a Virus in the Internet*, In 2014 IEEE 33rd International Symposium on Reliable Distributed Systems Workshops, refereed, SRDSW14, p.14-19, 2014.
DOI: 10.1109/SRDSW.2014.26

〔学会発表〕（計１件）
(1) François Bonnet, *Asynchronous Gathering in Rings with 4 Robots*, In Workshop on Distributed Robotic Swarms, 5/10/2015, Arcadia Ichigaya hotel, Chioda-ku, Tokyo.

〔図書〕（計０件）

〔産業財産権〕
○出願状況（計０件）

○取得状況（計０件）

〔その他〕
ホームページ等

６．研究組織

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