東北大学 電気通信研究所

研究室外部評価資料

(2013 年度-2018 年度)

Activity Report of Research Laboratory for External Review

April 2013 - March 2019
(FY.2013-2018)

Research Institute of Electrical Communication

Tohoku University

実世界コンピューティング研究室

Real-world computing

A. 研究室名 / Research Laboratory

実世界コンピューティング研究室
Real-world computing

B. 構成員 / Faculty and Research Staff (as of May 1, 2019)

※ 欄を適宜追加削除等調整して下さい．期間内に異動等があった場合には，在籍期間を記載して下さい．

教授 / Professor	
氏名 Name	石黒 章夫 Akio Ishiguro (April 2011 -)
分野名 Research Field	実世界コンピューティング研究分野 Real-world computing
准教授 / Associate Professor	
氏名 Name	加納 剛史 Takeshi Kano (Oct. 2016-)
分野名 Research Field	実世界数理モデリング研究分野 Real-world mathematical modeling
助教 / Assistant Professor	
氏名 / Name	福原　洸 / Akira Fukuhara (Oct. 2018-)
他 / Others	

C. 研究目的 / Research Purpose

本研究室では，生物ロコモーション等を題材に採りあげ，生物実験・数理モデリング・ロボット実機実験を通して，自律分散制御の体系的な設計原理の構築を目指した研究を行っている．

Our research group aims to establish a systematic design method for autonomous decentralized control by studying animal locomotion *etc.*, based on biological experiment, mathematical modeling, and robot experiment.

D. 主な研究テーマ / Research Topics

1. 脚式ロコモーションに内在する自律分散制御則の解明
2. ヘビ・ミミズ等が示す這行運動に内在する自律分散制御則の解明
3. クモヒトデのレジリエントな振る舞いに内在する自律分散制御則の解明
4. 自律分散制御の観点から探る古生物のロコモーション様式
5. バクテリア集団が示すサバイバビリティの発現機序解明
6. 交通流の自律分散制御の設計論構築

1. Understanding of decentralized control mechanism underlying legged locomotion
2. Understanding of decentralized control mechanism underlying crawling locomotion (snakes, earthworms *etc.*)
3. Understanding of decentralized control mechanism underlying resilient locomotion of brittle stars
4. Elucidation of locomotion patterns of ancient animals from the viewpoint of decentralized control
5. Understanding of the mechanism of survivability inherent in bacteria collectives
6. Designing decentralized control scheme for traffic flow

E. 学術論文等の編数 / The Number of Research Papers

	2013	2014	2015	2016	2017	2018	Total
(1) 査読付学術論文 Refereed journal papers	3	3	2	5	8	3	24
(2) 原著論文と同等に扱う 査読付国際会議発表論文 Full papers in refereed conference proceedings equivalent to journal papers	0	0	0	0	0	0	0
(3) 査読付国際会議 Papers in refereed conference proceedings	8	7	10	8	5	8	46
(4) 査読なし国際会議・シンポジウム等 Papers in conference proceedings	0	1	0	0	0	1	2
(5) 総説・解説 Review articles	0	1	2	1	0	0	4
(6) 査読付国内会議 Refereed proceedings in domestic conferences	1	2	0	0	0	0	3
(7) 査読なし国内研究会・講演会 Proceedings in domestic conferences	7	19	17	23	20	15	101
(8) 著書 Books	1	0	0	1	1	2	5
(9) 特許 Patents	0	1	0	1	0	0	2
(10) 招待講演 Invited Talks	2	5	4	10	3	2	27

F. 特筆すべき研究成果 / Significant Research Achievements (FY.2013-2018)

See Ref. 1. "#" mark indicates research carried out at a former organization.

2013-2018 年度の研究成果（論文・特許など）のうち，前半（2013-2015 年度）と後半（2016-2018 年度）それぞれで代表的な数件（2-3 件程度ずつ）について，参考資料を引用して，その特徴と学術的意義などを簡単に紹介する．英文のみ，もしくは和文と英文で記載．要約は 300 字程度．論文誌の要約/Abstract のコピー可．学術面での国際的インパクトならびに社会的影響を 100 字程度で記載．
必ずしも当該期間内に発表・出版したものに限るのではなく，例えば過去に発表したものでもこの期間内に成果が得られたり，評価されるようになったりしたものも含むものとする．
インパクトファクターや被引用件数など，できる限り第三者が定量的に評価できる指標を用いてアピールすること．それらの指標にはそぐわない場合には，その事情とそれに変わる適当な評価指標・尺度を示すこと．

[2013-2015]

1. D. Owaki, T. Kano, K. Nagasawa, A. Tero, and A. Ishiguro, "Simple Robot Suggests Physical Interlimb Communication is Essential for Quadruped Walking", J. Roy. Soc. Int, **10**(78), 20120669 (2013) [IF: 3.355], [Times Cited: 109]

Abstract: Quadrupeds have versatile gait patterns, depending on the locomotion speed, environmental conditions and animal species. These locomotor patterns are generated via the coordination between limbs and are partly controlled by an intraspinal neural network called the central pattern generator (CPG). Although this forms the basis for current control paradigms of interlimb coordination, the mechanism responsible for interlimb coordination remains elusive. By using a minimalistic approach, we have developed a simple-structured quadruped robot, with the help of which we propose an unconventional CPG model that consists of four decoupled oscillators with only local force feedback in each leg. Our robot exhibits good adaptability to changes in weight distribution and walking speed simply by responding to local feedback, and it can mimic the walking patterns of actual quadrupeds. Our proposed CPG-based control method suggests that physical interaction between legs during movements is essential for interlimb coordination in quadruped walking.

International impact on both academic and social aspects: This work showed that interlimb coordination of quadrupeds can be described by an extremely simple control scheme. The proposed control scheme enabled to reproduce various locomotion patterns of quadrupeds. This result imparted a great impact in the fields of biology and robotics, and this paper was cited 109 times. This work was also awarded in IEEE/RSJ International Conference on Intelligent Robots and Systems, one of the highest rank international conferences in the field of robotics.

[2016-2018]

2. D. Owaki and A. Ishiguro, "A Quadruped Robot Exhibiting Spontaneous Gait Transitions from Walking to Trotting to Galloping," *in Scientific Reports*, **7**, 277 (2017) [IF: 4.122], [Times Cited: 45]

Abstract: The manner in which quadrupeds change their locomotive patterns—walking, trotting, and galloping—with changing speed is poorly understood. In this paper, we provide evidence for interlimb coordination during gait transitions using a quadruped robot for which coordination between the legs can be self-organized through a simple "central pattern generator" (CPG) model. We demonstrate spontaneous gait transitions between energy-efficient patterns by changing only the parameter related to speed. Interlimb coordination was achieved with the use of local load sensing only without any preprogrammed patterns. Our model exploits *physical communication* through the body, suggesting that knowledge of physical communication is required to understand the leg coordination mechanism in legged animals and to establish

design principles for legged robots that can reproduce flexible and efficient locomotion.

International impact on both academic and social aspects: It was shown in this work that the gait transition from walk to trot to gallop can be reproduced by the control scheme proposed in the previous work (D. Owaki et al., J. Roy. Soc. Int., **10**, 20120669 (2013)) for the first time. This study shed new light on the mechanism of quadruped gait transition which has long remained elusive. This achievement was press released and introduced in many newspapers, journals, and web cites such as electronics weekly, IT media, Nikkei-sangyo Shimbun, Nikkan-kogyo Shimbun, and Kodomo-no-kagaku.

3. T. Kano, E. Sato, T. Ono, H. Aonuma, Y. Matsuzaka, A. Ishiguro, A Brittle Star-like Robot Capable of Immediately Adapting to Unexpected Physical Damage, Royal Society Open Science, **4**, 171200 (2017) [IF: 2.504], [Times Cited: 10]

Abstract: A major challenge in robotic design is enabling robots to immediately adapt to unexpected physical damage. However, conventional robots require considerable time (more than several tens of seconds) for adaptation because the process entails high computational costs. To overcome this problem, we focus on a brittle star—a primitive creature with expendable body parts. Brittle stars, most of which have five flexible arms, occasionally lose some of them and promptly coordinate the remaining arms to escape from predators. We adopted a synthetic approach to elucidate the essential mechanism underlying this resilient locomotion. Specifically, based on behavioural experiments involving brittle stars whose arms were amputated in various ways, we inferred the decentralized control mechanism that self-coordinates the arm motions by constructing a simple mathematical model. We implemented this mechanism in a brittle star-like robot and demonstrated that it adapts to unexpected physical damage within a few seconds by automatically coordinating its undamaged arms similar to brittle stars. Through the above-mentioned process, we found that physical interaction between arms plays an essential role for the resilient inter-arm coordination of brittle stars. This finding will help develop resilient robots that can work in inhospitable environments. Further, it provides insights into the essential mechanism of resilient coordinated motions characteristic of animal locomotion.

International impact on both academic and social aspects: This work proposed a decentralized control scheme that enables immediate adaptation to unexpected physical damages by drawing inspiration from brittle stars. This is a significant breakthrough as robots are increasingly expected to function in tough environments under hazardous conditions. This achievement was press released and introduced in many newspapers and web cites such as Nihon-keizai Shimbun, Nikkan-kogyo Shimbun, Science Daily, New Atlas, and Electronics 360. This work was also awarded in a domestic conference (best research award in SSI2014).

4. T. Kano, Y. Ikeshita, A. Fukuhara, and A. Ishiguro, Body-limb coordination mechanism underlying sea roaches' speed-dependent gait transition, Scientific reports, **9**, 2848 (2019) [IF: 4.122], [Times Cited: 1]

Abstract: The sea roach is an isopod with 14 legs; owing to its many degrees of freedom and coordination thereof, it can walk rapidly on rough terrain. Although there likely exists a remarkable decentralized control mechanism that facilitates fast and adaptive locomotion of sea roaches, it still remains elusive. To address this issue, we performed behavioural experiments and revealed that sea roaches often change their gait patterns depending on the locomotion speed. We suggest that the bending of the body trunk in the pitch direction is

essential for the gait transitions, and we propose a decentralized control mechanism for body-limb coordination. We demonstrate this with a sea-roach-like robot whose gait transition is achieved by the proposed mechanism. This mechanism has some points in common with control mechanisms proposed for other legged animals. Thus, our findings will help unveil the common principle of legged locomotion and aid the design of multi-legged robots that move like animals.

International impact on both academic and social aspects: In this work, it was found for the first time that sea roaches change their gait patterns as the locomotion speed increases, and this new result was reproduced by a sea roach-like robot with the proposed control mechanism. Sea roach is a key animal for understanding interlimb coordination mechanism of legged animals systematically because its number of legs is 14 – intermidiate between bipeds, quadrupeds *etc*. and myriapods. Hence, this work will have great impact on both robotics and biology fields.

G. 特筆すべき活動 / Significant Activities (FY.2013-2018)

See Ref. 2-9. "#" mark indicates research carried out at a former organization.

研究室外部評価参考資料の 2 以降を参照しながら，2013-2018 年度のなどの活動の中から特筆すべきものを取り出し，前半（2013-2015 年度）と後半（2016-2018 年度）に分けて簡単に紹介する．英文のみ，もしくは和文と英文で記載.

[2013-2015]

・Organization of conferences

The most important event during this period was the organization of the 25th symposium on autonomous decentralized systems, a major domestic conference in our field. Akio Ishiguro was the general chair, and Takeshi Kano and the laboratory members assisted him. The conference was successful.

・Research grants

With regard to research grants, Akio Ishiguro was the leader of robotics group in the two projects of JST CREST (2008-2013, Representative: Ryo Kobayashi of Hiroshima University, 107,100,000 yen in total; 2014-, Representative: Ryo Kobayashi of Hiroshima University, 79,130,000 yen in total). Akio Ishiguro was the representative of Grant-in-Aid for Scientific Research (A) from the MEXT (2012-2015, 30,300,000 yen in total) and the NEDO project (2014-2016 24,000,000 yen in total).

・Out-reach activities, education, and awards

Akio Ishiguro held lectures in several high schools. Our laboratory demonstrated bio-inspired robots in the evert "Science Agora" in 2014, and this demonstration was awarded (Risupia award). Akio Ishiguro and Takeshi Kano supervised 8 master course students and 8 bachelor course students from 2013 to 2015.

[2016-2018]

・Organization of conferences, editor of journals *etc.*

The most important event during this period was the organization of the AMAM 2017, a major international conference in our field. Akio Ishiguro was the general chair, and Takeshi Kano, Akira Fukuhara, and the laboratory members assisted him. The conference was successful. Akio Ishiguro and Takeshi Kano also contributed to the organization of Tohoku branch of the Society of Instrument and Control Engineers (SICE). Moreover, Akio Ishiguro was the associate editor of "Soft robotics", a high-rank journal in the field of soft robotics.

・Research grants

Akio Ishiguro gained a research grant of Human Frontier Science Program (HFSP), a high-rank research grant whose acceptance ratio is less than 5% (2017-, Representative: Auke Ijspeert of EPFL, 34,000,000 yen in total). He also joins the project of Grant-in-Aid for Scientific Research (S) from the MEXT (2017-, Representative: Koichi Osuka of Osaka University, 145,560,000 yen in total).

・Out-reach activities and education

Akio Ishiguro held lectures in several high schools. Akio Ishiguro and Takeshi Kano supervised 1 doctor course student, 15 master course students and 9 bachelor course students from 2016 to 2018.

・Awards

Akio Ishiguro received WIRED Audi INNOVATION AWARD, a prestigious award for innovative researches.