

Graduate School of Creative Science and Engineering
Waseda University

博士論文概要

Doctoral Thesis Synopsis

論文題目

Thesis Theme

View Systems for High Efficiency
Teleoperations for Unmanned Construction
based on Human Cognition Characteristics
無人化施工の高効率遠隔操作を目指した
ヒトの認知特性に基づく視覚情報提示手法

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Unmanned construction, which involves the teleoperation of construction machinery, has been introduced to areas affected by disasters such as earthquakes and volcanos. Such areas may be too dangerous for humans to enter. The unmanned construction machinery is controlled remotely by operators watching the views from cameras installed at the disaster sites. The crucial problem with unmanned construction is low efficiency; specifically, the work efficiency of unmanned construction is less than half that of ordinary on-board operation. Therefore, improving the efficiency of teleoperating heavy machinery under unmanned construction is crucially important. This thesis focuses on visual information for three cognitive reasons. First, humans acquire 70% of their information through their vision. Second, problems related to visual information are the most important in unmanned construction. Third, teleoperators mainly attend to visual information, ignoring other information for up to 30% of their teleoperation time.

Several researchers have developed visual support systems that provide information other than the simple images captured by machinery cameras. For instance, third-person views can be provided by drones or image processing, external cameras can be controlled to follow work states (e.g., grasping and releasing), and 3D and wide cab views can be obtained. These studies have provided various information to teleoperators.

However, as most of these studies do not consider human cognition characteristics, the systems impose excessive cognitive load on teleoperators. In previous studies, all information was provided to the operator during operations, requiring the teleoperators to simultaneously control the remote machinery and plan the moving paths and trajectories of the machinery arms. View systems to provide environmental information in advance are required to help the operators to plan their moving or grasping actions, reducing their cognitive load by removing the need to plan while working. Moreover, the techniques of previous studies provide no intuitive views (e.g., camera placement), although arbitrary third-person views are available. Furthermore, providing excessive information can cause cognitive tunneling, which focuses the teleoperators' attention on specific views while ignoring other views. Teleoperators are required to change their views depending on the work states. Therefore, a visual interface that avoids cognitive tunneling and attracts the operator's gaze to views appropriate for the work states is important to improve work efficiency.

In this thesis, the author develops a view system based on human cognition characteristics. In particular, the author addresses the following three technical challenges: (i) developing a view system that provides environmental information in advance, (ii) investigating the optimum and allowable camera placements, and (iii) developing a visual interface that avoids cognitive tunneling. The thesis is divided into five chapters.

Chapter 1 summarizes the unmanned construction system, the problems of unmanned construction, and the causes of low efficiency (the crucial problem of unmanned construction). The importance of visual information in enhancing the work efficiency is also explained. Related studies on visual information, the limitations of these studies, and the purpose of the present study are highlighted.

Chapter 2 develops a prior view system for inputting environmental information based on the characteristics

of a cognitive map, defined as a mental representation of the area. Cognitive maps can be roughly divided into two perspectives: survey and route perspectives. In the prior view system, the survey perspective is obtained through the third-person view of an arbitrary viewpoint, and the route perspective is obtained by a subjective view that can be changed by the teleoperator. Experimental results proved that the proposed prior view system can improve the quality and quantity of cognitive maps of important landmarks, including the target objects. Therefore, plans can be easily implemented in the proposed system. The acquisition of the survey perspective enables total planning, while the acquisition of the route perspective enables partial planning and improves the work efficiency. However, as some operators can forget their planned paths and trajectory, the author developed an augmented reality reminder which improves the work efficiency and eases the cognitive load.

Chapter 3 proposes an optimum and allowable camera placement for manipulation tasks. External views are essential even when teleoperators can watch wide 3D cab views. The author hypothesized an optimum and allowable area based on canonical views, which provide the highest performance in object recognition. Canonical views are characterized by minimal occlusion and an allowable rotation range of $\pm 30^\circ$, and are almost unaffected by object size. Thus, the optimal pan and tilt angles were expected as 90° because this angle gives the canonical view. Meanwhile, the allowable pan and tilt angles were hypothesized as $\pm 30^\circ$ to match the allowable rotation angles of the canonical views. The optimal and possible positions of the camera placements in manipulation tasks were experimentally investigated in a scale model and an actual machine with novice and skilled teleoperators as subjects. The experimental results are discussed and summarized. The results are applicable to camera-placement optimization in actual unmanned construction.

Chapter 4 develops a visual interface that avoids cognitive tunneling during teleoperation. Cognitive tunneling is caused by (i) focusing on views with high visual saliency, and (ii) low visual momentum. Visual saliency defines the ease of attracting a human's attention to an area, and visual momentum indexes the ease of integrating information through view transitions. The developed visual interface increases the visual momentum and attracts the teleoperator's eyes to views with low visual saliency. The visual momentum can be enhanced by including the same landmarks in the views of each work state. Moreover, human attention tends to focus on objects that vibrate at a specific frequency (5 Hz) in the effective field of view ($\pm 30^\circ$). Thus, whenever the work-state changes, the proposed interface displays a different external view within the teleoperator's effective viewing field, and vibrates it at 5 Hz for 0.5 s to capture the teleoperator's attention. The experimental results indicated that the proposed view system can decrease cognitive tunneling and improve the work efficiency in tasks requiring precise operations, such as grasping.

Chapter 5 summarizes the thesis and discusses the practical implementations of the proposed systems.

The developed view system is based on human cognition characteristics. A prior view system that inputs environmental information based on the characteristics of cognitive maps was first proposed. Next, an optimum and allowable camera placement based on the characteristics of canonical views was proposed, and was

investigated in a scale model and on actual machinery. Finally, a view interface that avoids cognitive tunneling by increasing the visual momentum and lowering the visual saliency of views. The effectiveness of the proposed view system was evaluated in experiments using a simulator, a scale model, and an actual machinery.

早稲田大学 博士（工学） 学位申請 研究業績書

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種 類 別 (By Type)	題名、 発表・発行掲載誌名、 発表・発行年月、 連名者 (申請者含む) (theme, journal name, date & year of publication, name of authors inc. yourself)
論文	<p>○ 無人化施工の掘削・リリース作業における側面カメラの最適および好適配置の実験的導出, 日本機械学会論文集, 2019.8, Vol. 85, No. 876, pp. 1-12, 佐藤隆哉, 亀崎允啓, 山田充, 橋本毅, 菅野重樹, 岩田浩康</p> <p>○ Development of a Cognitive Untunneling Multi-view System Based on Visual Momentum and Saliency for Teleoperators of Heavy Machines, Automation in Construction, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Satoshi Niuchi, Shigeki Sugano, and Hiroyasu Iwata (in press)</p> <p>○ A Basic Framework of View Systems Allowing Teleoperators to Pre-Acquire Spatial Knowledge from Survey and Route Perspectives, Presence, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Shigeki Sugano, and Hiroyasu Iwata (in press)</p>
講演 (査読有)	<p>○ A Low Cognitive Load and Reduced Motion Sickness Inducing Zoom Method Based on Typical Gaze Movement for Master-Slave Teleoperation Systems with HMD, 2020 IEEE/SICE International Symposium on System Integration (SII), pp. 28-33, 2020.1, Yuichi Mizukoshi, <u>Ryuya Sato</u>, Takahiro Eto, Mitsuhiro Kamezaki, Ayaka MATSUZAKA, Yang Liu, Akio Namiki, Asaki Imai, Takashi Matsuzawa, Kenji Hashimoto, Atsuo Takanishi, Hiroyasu Iwata</p> <p>○ Experimental Investigation of Optimum and Allowable Range of Side Views for Teleoperated Digging and Release Works by Using Actual Construction Machinery, 2019 IEEE/SICE International Symposium on System Integrations (SII 2019), pp. 788-793, 2019.1, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Mitsuru Yamada, Takeshi Hashimoto, Shigeki Sugano, and Hiroyasu Iwata</p> <p>○ Derivation of an Optimum and Allowable Range of Pan and Tilt Angles in External Sideway Views for Grasping and Placing Tasks in Unmanned Construction Based on Human Object Recognition, 2019 IEEE/SICE International Symposium on System Integrations (SII 2019), pp. 788-793, 2019.1, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Satoshi Niuchi, Shigeki Sugano, and Hiroyasu Iwata</p> <p>○ A Pre-offering View System for Teleoperators of Heavy Machines to Acquire Cognitive Maps, The 15th IEEE International Symposium on Safety, Security and Rescue Robotics (SSRR2017), pp. 61-66, 2017.10, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Shigeki Sugano, and Hiroyasu Iwata</p>

早稲田大学 博士（工学） 学位申請 研究業績書

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種 類 別 By Type	題名、 発表・発行掲載誌名、 発表・発行年月、 連名者（申請者含む）(theme, journal name, date & year of publication, name of authors inc. yourself)
講演 (査読有) ○	<p>Investigation on Effect of Angular Deviation from Perpendicular Line to Lateral View Camera on Work Efficiency for Teleoperated Construction Machines, The 34th International Symposium on Automation and Robotics in Construction (ISARC2017), paper no. P06, 2017.6, Satoshi Niuchi, Mitsuhiro Kamezaki, <u>Ryuya Sato</u>, Shigeki Sugano, and Hiroyasu Iwata</p> <p>Pre-offering Work-Site Views to Acquire Spatial Knowledge from Survey and Route Perspective for Advanced Teleoperation of Construction Machines, The 34th International Symposium on Automation and Robotics in Construction (ISARC2017), paper no. P05, 2017.6, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Satoshi Niuchi, Shigeki Sugano, and Hiroyasu Iwata</p> <p>Gaze Pattern Analysis in Multi-Display Systems for Teleoperated Disaster Response Robots, A Satellite Conference of 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC JUNIOR 2016), paper no. 2017, 2016.10, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Shigeki Sugano, and Hiroyasu Iwata</p> <p>Visual Attention to Appropriate Monitors and Parts Using Augmented Reality for Decreasing Cognitive Load in Unmanned Construction, 6th International Conference on Advanced Mechatronics 2015 (ICAM2015), page 45 (1A1-23), 2015.12, <u>Ryuya Sato</u>, Mitsuhiro Kamezaki, Junjie Yang, Shigeki Sugano, and Hiroyasu Iwata</p> <p>Performance Analysis in Advanced Tele-operation System Based on Introduction of Danger-Avoidance View, 8th International Conference on Intelligent Robotics and Applications (ICIRA2015), pp. 401-412, 2015.8, Junjie Yang, Mitsuhiro Kamezaki, <u>Ryuya Sato</u>, Hiroyasu Iwata, and Shigeki Sugano</p> <p>Inducement of Visual Attention Using Augmented Reality for Multi-Display Systems in Advanced Tele-operation, 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2015), pp. 5364-5369, 2015.9, Junjie Yang, Mitsuhiro Kamezaki, <u>Ryuya Sato</u>, Hiroyasu Iwata, and Shigeki Sugano</p> <p>無人化施工における奥行感の把握が必要な手先作業時における外部カメラの最適・好適配置の実験的導出, 第19回建設ロボットシンポジウム論文集(SCR2019), 2019.10, <u>佐藤隆哉</u>, 亀崎允啓, 山田充, 橋本毅, 菅野重樹, 岩田浩康 (発表予定)</p> <p>重機の遠隔操作性向上のためのマルチカメラ最適配置に関する研究— 第二報 掘削・配置作業におけるパン・チルト角が及ぼす作業効率への影響の実験的検証 —, 第24回ロボティクスシンポジウム講演論文集, pp. 14-17, 2019.3, <u>佐藤隆哉</u>, 亀崎允啓, 山田充, 橋本毅, 菅野重樹, 岩田浩康</p> <p>ダンプトラックの燃費向上・長寿命化に向けた状態識別に関する基礎検討, 第18回建設ロボットシンポジウム論文集(SCR2018), paper no. O1-5, 2018.9, 山村真司, 亀崎允啓, <u>佐藤隆哉</u>, 菅野重樹, 岩田浩康</p>

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講演 (査読有)	<p>重機の遠隔操作性向上のためのマルチカメラ最適配置に関する研究－第一報 パン・チルト角による作業性への影響の検証－, 第23回ロボティクスシンポジウム講演論文集, pp. 267-272, 2018.3, 仁内智志, 亀崎允啓, <u>佐藤隆哉</u>, 菅野重樹, 岩田浩康</p> <p>ヒトの認知構造に基づいた事前の環境把握映像提示による災害対応遠隔重機作業の効率化に関する研究, 第17回建設ロボットシンポジウム論文集(SCR2017), paper no. O3-2, 2017.8, <u>佐藤隆哉</u>, 亀崎允啓, 仁内智志, 菅野重樹, 岩田浩康</p> <p>遠隔操作オペレータの環境把握性を高める非映像化情報の可視化と推奨注視映像への誘導, 第21回ロボティクスシンポジウム講演論文集, pp. 50-55 (1C1), 2016.3, 亀崎允啓, <u>佐藤隆哉</u>, 楊俊傑, 岩田浩康, 菅野重樹</p> <p>無人化施工における視覚情報の強化に関する研究－作業状況に応じた環境カメラの自動制御と拡張現実技術を用いた注視支援－, 第15回建設ロボットシンポジウム論文集(SCR2015), paper no. O-24, 2015.9, 亀崎允啓, <u>佐藤隆哉</u>, 楊俊傑, 岩田浩康, 菅野重樹</p>
講演 (査読無)	重機の遠隔操作性向上のためのマルチカメラ最適配置に関する研究－ 第三報 搭乗操作熟練者における掘削・配置作業でのパン・チルト角が及ぼす作業効率への影響の実験的検証－, 第37回日本ロボット学会学術講演会, paper no. 2A1-05, 2019.9, <u>佐藤隆哉</u> , 亀崎允啓, 山田充, 橋本毅, 菅野重樹, 岩田浩康
その他 (講演) (査読有)	【他 17 件】
その他 (講演) (査読無)	Investigating the Relationship between Connection, Agency and Autonomy for Controlling a Robot Arm for Remote Social Physical Interaction, 21st International Conference on Human-Computer Interaction (HCI International 2019), pp. 277-290, 2019. 7, <u>Ryuya Sato</u> , Don Kimber, Yanxia Zhang
その他 (特許)	【他 2 件】
その他 (研究費)	Innovation of Railway System, IEEE International Symposium on Railway System (ISRS2015), 2015.11, <u>Ryuya Sato</u> , Tamon Miyake, Satoshi Funabashi, and Kinji Mori
その他 (特許)	【他 1 件】
その他 (研究費)	路網ルート設計装置及びそのプログラム、並びに路網ルート生成表示システム, 特開2017-201936, 2017.11, 白井裕子, 野澤直樹, 藤井祥万, <u>佐藤隆哉</u> , 加藤卓哉
その他 (受賞)	立石科学技術振興財団 研究助成 (C) 採択 2018.4 - 現在
その他 (受賞)	日本学術振興会特別研究員 DC2 研究奨励費 2019.04 - 現在
	【他 1 件】
	日本機械学会三浦賞, 2017.3
	【他 1 件】