論文 / 著書情報
Article / Book Information

題目(和文)	マルチエージェントシステムのための光無線通信
Title(English)	Visible Light Communication for Autonomous Multiagent Systems
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出典(和文)	学位:博士(工学), 学位授与機関:東京科学大学, 報告番号:甲第367号, 授与年月日:2025年3月26日, 学位の種別:課程博士, 審査員:下坂 正倫,DEFAGO XAVIER,村田 剛志,鄭 顕志,金崎 朝子
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Institute of Science Tokyo, Report number:甲第367号, Conferred date:2025/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

The integration of robotics into diverse applications, ranging from industrial to consumer and household domains, has been facilitated by advancements in deep learning and robotics technologies. Multi-agent systems, in particular, are gaining attention due to their potential for cooperative behavior in tasks such as resource exploration, environmental monitoring, and delivery services. The Centralized Training Decentralized Execution (CTDE) framework has become a standard for multi-agent reinforcement learning, enabling distributed execution through stable communication.

Despite these advancements, challenges persist, especially concerning radio-frequency (RF) communication and agent identification. RF-based communication is commonly employed in current systems. Still, its limitations include restricted resources, susceptibility to interference, and ineffectiveness in certain environments, such as underwater regions or electromagnetic-sensitive areas. Furthermore, agent identification methods based on visual markers like ArUco or location-based systems like GPS often fall short in dynamic scenarios involving fast-moving agents, such as drones, or environments with low positional accuracy.

Visible Light Communication (VLC) is a promising alternative to address these challenges. VLC employs light emitted from LEDs or lasers to transmit modulated signals, which are then received and demodulated by photodiodes or cameras. Compared to RF communication, VLC offers advantages such as suitability in environments where RF is infeasible (e.g., underwater), license-free operation, and integration with visual data. However, VLC is inherently constrained by its straight-line propagation, susceptibility to light interference, and inability to penetrate obstacles.

Three key applications of VLC are explored in this thesis: general communication, ID communication, and self-localization. General communication involves transmitting shared data such as position or velocity, often replacing RF communication. ID communication leverages VLC's directional characteristics to identify agents within the field of view (FOV). Self-localization employs multiple LEDs and cameras to estimate positional relationships, enabling agents to determine their location and orientation using methods similar to marker-based localization but with time-based blinking patterns.

Two illustrative scenario examples highlight the potential of VLC. In the first, multiple drones coordinate to capture images in complex outdoor environments for 3D reconstruction. Existing systems face difficulties in providing precise localization and identification in such settings, especially when using GPS or visual markers like ArUco. The second scenario involves underwater drones, where wireless communication is limited, and wired communication hampers decentralized coordination. VLC's ability to operate in such constrained environments positions it as a viable solution for enabling effective multi-agent cooperation.

The thesis is organized into three parts. Part I focuses on algorithms for multi-agent reinforcement learning using VLC. Standard algorithms often assume constant communication, but VLC's FOV constraints necessitate new methods. The proposed algorithm enables agents to predict unseen areas and optimize visual orientation for better coordination. Simulations and real-world experiments validate the effectiveness of this approach, demonstrating performance improvements comparable to RF communication.

Part II examines the enhancement of individual identification capabilities through innovations in VLC receiving devices. Conventional photodiodes lack spatial resolution, while RGB cameras, though capable of high resolution, suffer from low frame rates. Event cameras, a novel technology, overcome these limitations by detecting brightness changes with high temporal resolution. By leveraging event cameras for VLC, this research achieves robust identification and communication, outperforming methods using ArUco markers or RGB cameras.

Part III explores applications of VLC, particularly for self-localization in multi-agent systems. By utilizing event cameras, the system achieves robust communication for high-speed agents and individual identification tasks. Relay communication between agents was demonstrated in experiments to enable accurate self-localization even when transmitters were outside the FOV, confirming its advantages over other self-localization methods in specific environments.

These findings contribute to advancing the realization of the future vision for multi-agent systems, which are currently considered difficult to implement. For instance, the proposed algorithm for VLC-based coordination can significantly enhance the feasibility of multi-agent cooperation in underwater environments, where radio-based information sharing is challenging. Additionally, by employing event cameras, the system can facilitate individual identification and information sharing, even for high-speed drones. Furthermore, in dynamic environments such as urban areas with moving objects and people, where GPS and other self-localization methods cannot be used, the proposed multi-agent system enables robust, real-time self-localization. This opens the door to various applications such as 3D reconstruction, inspection, and surveillance.