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論文の内容の要旨

Unlike two-dimensional (2D) representations, such as pictures, three-dimensional (3D) objects can be uneven, and when they are viewed from certain directions, some parts cannot be seen. To grasp the full picture, it is necessary to look around the object, and the parts that cannot be seen must always be filled in by the imagination. The more complex the shape, the more imagination is required. For this reason, the creation of 3D objects, such as building blocks and LEGO, develops human creativity. However, individual creativity has its limits, and the creation of large or complex 3D objects requires the collaboration of multiple people. Co-creation makes it possible to share and combine ideas and information. In collaborative creation, creators cooperate to achieve a common goal, giving them a sense of accomplishment and unity in their production activities and a fulfilling creation experience.

Collaborators are essential to co-creation, and flexible collaboration, efficient work, and cooperation among creators are key elements. In addition, mutual understanding through information sharing and communication is essential to achieve common goals. Having confidence in the results of one's work and a sense of contribution are other important elements in gaining satisfaction and fulfillment through co-creation and are achieved through active participation in activities. Hence, co-creation is composed of various elements and forms the basis for creative outcomes. In production activities, in particular, the sharing of ideas and information creates value that cannot be achieved by individuals alone. Therefore, it is important to understand and share the overall picture of creation, the steps of production, and efficient methods as well as to work together to achieve the goal. However, levels of knowledge, experience, and skills related to production vary among individuals, leading to discrepancies in the information shared and uneven progress in production. For those who are unfamiliar with production activities, in particular, such difficulties can lead to a lack of motivation and sense of contribution, a mismatch in the pace of production, and creator isolation, which can hinder the fulfilling experience that co-creation can offer. Therefore, it is important to create an environment in which everyone recognizes a common goal and can collaborate while sharing a sense of accomplishment and enjoyment. To promote such an environment, it is necessary to

support the process of collaborative creation.

To address this issue, this thesis proposes a method to promote collaborative creation that addresses three key elements of collaborative activities: 1) clarifying the final product image and deepening the understanding of common production goals, 2) facilitating large-scale production to understand and share efficient production methods, and 3) promoting a sense of unity among makers to enhance a sense of unity and thus prevent isolation and lack of communication. Moreover, the thesis aims to realize the proposed methods by using augmented reality (AR) technology, which presents visual and tactile information to s and is the focus of attention in various research fields as an information medium. In AR, visual information through information projection can superimpose virtual content in the real world. In addition, haptic information using small actuators can instantly present clear sensations to users without interfering with their visual or auditory senses. Therefore, these technologies are used for play, education, sports support, tactile reproduction in virtual spaces, navigation, and other applications.

In Methods 1 and 2, we use spatial augmented reality (SAR) technology facilitated by projectors. SAR enables the highly integrated overlaying of virtual content onto the real world, allowing for the natural integration of the projected content and information sharing among multiple users. Therefore, SAR is well suited for presenting information for the collaborative creation of large-scale 3D objects. In Methods 1 and 2, we propose a method for visualizing production objects in real space using SAR to achieve large-scale production.

Method 1. Clarifying the final image of the production subject: Observing objects through touch enables a detailed grasp and an intuitive understanding of the shape and scale of the production subject. To facilitate these outcomes, we propose a real-time projection system using SAR to project distorted images with the aim of achieving natural interaction with the projected content. The proposed method presents lifelike images to users without the use of physical displays, such as smartphones or AR glasses. Constantly presenting stereoscopic images that are responsive to the user's viewpoint enables users to gain a prior understanding of the shape and scale of the 3D object.

Method 2. Facilitating the creation of large-scale 3D objects: Presenting clear production procedures and methods enables even those without knowledge of or skills in production activities to understand and share efficient production methods. To achieve this outcome, we use SAR to interactively visualize the production steps of the creation subject, providing creators with intuitive and accurate material placement locations. This approach allows creators to effectively collaborate on a single goal and produce large-scale 3D objects as tall as a person, which would be impossible for an individual to do.

Method 3. Enhancing unity among creators with a haptic presentation approach: We

implement a haptic presentation system using pneumatic actuators to improve the sense of unity among creators. To achieve this, we develop a device that presents the production actions of others as haptic sensations on the creator's neck, enabling them to understand the actions of the collaborators. This approach allows creators to comprehend the production status of the collaborators, facilitating efficient collaboration in the production process.

The research on Method 1 revealed that the real-time deformation of distorted images improves the realism of the projected content and has the effect of making it possible to see and interact with the projected image as if it were a real object. This effect allows the natural movement of the production object, as if the user were observing a real body, and contributes to clarifying the image of the completed production goal necessary for collaborative creation.

The research on Method 2 demonstrated that presenting interactive production procedures through information projection enables accurate material placement, which eases large-scale production. Collaborative production activities in such large-scale projects contribute to the enjoyment, fun, and shared sense of accomplishment, fostering the necessary communication for collaborative creation. Moreover, the proposed method involves processing the production subject computationally and recreating it in the real world using common materials, such as balloons, plastic bottles, or cans. Therefore, it facilitates the creation of artistic expressions and innovative designs, generating creative value.

The research on Method 3 revealed that grasping the actions of others through haptic presentations makes the participants imagine the situation of others and improves the sense of unity. These outcomes have the effect of preventing creator isolation, as creators can match each other's pace of creation, and of promoting conversation. Such production activities enable the sharing of ideas and information necessary for collaborative creation and contribute to the building of cooperative relationships. The sharing the ideas or information facilitates creative processes, such as collaboration and the acquisition of inspiration.

These approaches focus on essential elements for co-creation in production activities. Understanding and sharing the image of the completed production object, production procedures, and efficient production methods, as well as achieving the goal through cooperation, enable a sense of accomplishment and enjoyment of the production process to be shared. It is expected that working in this way will lead to the realization of fulfilling production activities.

Keywords: *Production Support, Projection Mapping, Haptic, collaborative creation, Augmented Reality*

論文審査の結果の要旨

本博士論文は、3 次元オブジェクトに対する協働創造を促進するための、以下の 3 つの課題に取り組んだ研究である。1）最終的な制作物のイメージを明確にし、共通の制作目標への理解を深める、2）大規模なオブジェクトの効率的な制作方法の理解を促進する、3）作り手同士の一体感を高め、孤立やコミュニケーション不足を防ぐ。以下に、具体的に述べる。

1）人は触って観察することで、制作対象の形状やスケールを詳細に把握し、直感的に理解することができる。そこで、投影されたコンテンツとの自然なインタラクションを目指し、AR(拡張現実)を用いて実在感のある立体映像を投影するシステムを提案した。制作者の視点に応じた立体画像を提示することで、制作者は制作対象物を直感的に理解することができる。

2) 制作の手順や方法をわかりやすく提示することで、制作活動の知識やスキルがない人でも、効率的な制作方法を理することができる。そのために、AR を用いて制作対象の制作手順をインタラクティブに可視化し、直感的で正確な素材配置法を提供するシステムを提案した。この手法により、制作者が共通の目標に向かって効率的に共同作業を行い、個人では不可能な、人の背丈ほどもある大規模な 3D オブジェクトを制作することを確認した。

3) 空気圧アクチュエータを用いた触覚提示システムを実装し、制作者間の一体感を向上させるシステムを提案した。提案システムでは、制作者の首筋に共同制作者の制作行為を触覚として提示する装置を用い、視聴覚情報に頼らずに他者の行為を理解できるようにしている。この手法により、制作者は共同制作者の制作状況を把握することができ、制作プロセスにおける効率的なコラボレーションを促進することができる。

これらのアプローチは、創作活動における共創に不可欠な要素に着目したものである。制作物の完成イメージ、生産手順、効率的な生産方法などを理解・共有し、協力してゴールを目指すことで、生産活動の達成感や楽しさを共有することができる。このような働きかけが、充実した生産活動の実現につながることが期待される。

このように、本研究は 3 次元オブジェクトの協創創造という知識創造活動を支援するための新規かつ有用な技術を実現している点で、学術的に貢献するところが大きい。よって博士（知識科学）の学位論文として十分価値あるものと認めた。