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論　文　題　目	A Manual Assembly Process Virtual Training System with Automatically Generated Augmented Feedback		
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論文の内容の要旨

Manual assembly training traditionally relies on experienced operators to guide trainees through task demonstrations, trials, evaluations, and discussions. This method, while effective, is limited by the availability of experts. Current virtual training systems (VTS) focus on delivering rich multimedia content for task demonstrations, reducing dependence on experts. However, these systems often lack automated, comprehensive, augmented feedback for trainees.

This research introduces EXAMINER (**EX**pert Independent Manual **A**sse**M**bly V**I**rtual Trai**NER**), a system that objectively evaluates and provides feedback on trainees' motor and cognitive skills in manual assembly tasks. By automating feedback, EXAMINER enhances training accessibility and reduces reliance on experts. This study explores the digitization of human skills, objective measurement techniques, and the integration of these elements into an effective training system. The proposed system is evaluated for its ability to deliver appropriate feedback based on trainee performance, aiming to improve training outcomes and adoption rates.

The resulting framework consists of the following components: skill digitization, skill comparison, feedback provider, and multimedia training material. The implementation focuses on the first three components, ensuring their seamless integration. The framework implementation utilized methodologies for skill digitization using a video camera, employing standard and contemporary techniques such as deep learning in computer vision for human pose estimation, recurrent neural networks for activity recognition, and computer vision for contextual sensing. Each underlying subcomponent shows promising performance.

The digitization process is critical because it is the foundation for subsequent skill analysis and comparison between trainees and experts. In analyzing these operations, the study takes a novel approach, employing algorithms such as edit distance and dynamic time warping to identify and quantify skill differences. This methodology enables a more in-depth understanding of manual assembly cognitive and motor skill differences.

Another contribution of this research is the introduction of the I-MA task data model. This model enhances the framework's adaptability across diverse training scenarios and revolutionizes how information is systematically organized and utilized within I-VTS. The modular design of the framework, emphasizing interconnected yet distinct components, significantly enhances system flexibility and scalability, catering to a wide range of training needs and environments.

In summary, this research offers a comprehensive, flexible, and efficient I-VTS framework, representing a significant leap forward in virtual training systems. The framework utilizes advanced digitization techniques, detailed skill analysis, and user-friendly augmented feedback to address current gaps in I-MA training and establish a new standard for future developments in the field.

Keywords: Deep learning, Computer vision, Manual assembly, Virtual training, Industry 4.0

論文審査の結果の要旨

Traditionally, manual assembly training in manufacturing relies on experienced operators to guide trainees through task demonstrations, trials, evaluations, and discussions. This method, while effective, is limited by the availability of human experts. Recently, thanks to the development of human-computer interaction and virtual reality technology, virtual assembly training systems have emerged as an important tool in modernizing and enhancing the training processes for assembly tasks in the era of Industry 4.0. The main objective of this dissertation is to develop a manual assembly process virtual training system with automatically generated augmented feedback for trainees on their cognitive skills in assembly tasks. The main contributions are summarized as follows.

This research developed the so-called EXAMINER (EXpert Independent Manual AsseMbly VIrtual TraiNER) system that is capable of objectively evaluating and providing feedback on trainees' motor and cognitive skills in manual assembly tasks so as to enhance training accessibility while reducing reliance on experts. The proposed system was tested and evaluated for its ability to deliver appropriate feedback based on trainee performance, aiming to improve training outcomes and adoption rates. Further contribution of this dissertation is the introduction of the industrial manual assembly (I-MA) task data model to enhance the proposed system's adaptability across diverse training scenarios and revolutionize how information is systematically organized and utilized within industrial virtual assembly training systems.

This dissertation has made significant contributions both theoretically and practically in the field of manual assembly training. The research work presented in this dissertation has resulted in two journal papers and one refereed conference paper.

In summary, Mr. SINGHAPHANDU Raveekiat has completed all the requirements in the doctoral program of the School of Knowledge Science, JAIST and finished the examination on August 08, 2024, all committee members approved awarding her a doctoral degree in Knowledge Science.

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