（様式 5）

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学位（博士）論文要旨

(Doctoral thesis abstract)

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論 文 題 目 (Title)	A Study on Clustering-based Marking using Deep Neural Networks for Online Handwritten Mathematical Answers オンライン手書き数式解答に対する深層ニューラルネットワークを用いたクラスタリングに基づく採点の研究

論文要旨（2000 字程度）
(Abstract(400 words))
※欧文・和文どちらでもよい。但し、和文の場合は英訳を付すこと。
(in English or in Japanese)

This thesis presents a study on clustering-based marking using deep neural networks for online handwritten mathematical answers. In education, descriptive math questions are considered to be better than multiple-choice math questions to evaluate students' understanding and abilities to answer. However, examiners need to scan and score a large number of answers, which requires a huge amount of time and effort. Clustering-based marking is a promising approach to help examiners to mark handwritten answers. In this thesis, we present three main contributions: (1) we present our strategy and two tools (e-testing tool and e-marking tool) for collecting and annotating handwritten descriptive answers, (2) we present two approaches for clustering online handwritten mathematical expressions (OHMEs), (3) we present two methods for improving OHME recognition.

First, we propose an e-testing tool on a tablet, which works as the pattern collection tool, and an e-marking tool as the annotation tool for creating a dataset of handwritten math answers (HMAs) for descriptive questions. We present specifications and workflows of those tools in detail. By providing the e-testing tool and the e-marking tool, we plan to collaborate with other organizations for collecting a large dataset, then publish it for the research community.

Secondly, we propose two approaches for clustering OHMEs to create a clustering-based marking. To the best of our knowledge, we are the first group attempting to cluster OHMEs. Mathematical expressions are 2D-structural and infinite combinations of math symbols and spatial relationships. Our first approach is to extract features from low-level pattern features to high-level symbolic and structural features obtained from processing and recognizing OHMEs. The second approach is to compute pairwise similarities among OHMEs. We achieved the best results of around 0.916 and 0.915 for purity and around 0.556 and 0.702 for the marking cost on two answer datasets, Dset_Mix and NIER_CBT, respectively.

Thirdly, we propose two methods for improving OHME recognition. Since our proposed clustering methods utilize the recognition results of OHMEs, we aim to improve the recognition rate for improving the performance of the clustering process. The first method is to utilize bidirectional context from input stroke sequences for symbol segmentation and classification. The second method is to utilize a math language model combined with OHME recognizers. We propose the first transformer-based math language model which can combine with both online and offline HME recognizers. Experiments showed that our proposed methods can improve the performance of OHME recognizers.

（英訳）※和文要旨の場合(400 words)