Towards Automatic VR Scene Generation for Safety Training Scenarios Using Manually Annotated 3D Object and Spatial Relation Data

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Abstract

Virtual Reality (VR) is used for safety training to provide realistic practice in a controlled setting. Manual VR training development is time-consuming, limited in realism, and may omit critical accident factors due to human interpretation. To address this, an annotated dataset of 100 real accident reports has been developed to train NLP models to predict the 3D objects and relations involved in accidents. These predictions are stored in a structured JSON file for automatic scene generation. The generation approach enables rapid, realistic, and consistent VR training. The evaluation of the annotated dataset shows high reliability in labeling (96% for objects, 99% for relations); consistency indicates 813 cases were reviewed, including 644 valid cases, 135 revised cases, and 34 removed cases; the annotated dataset confirms high usability (precision is 0.7444, recall is 0.8000, and F1 is 0.771 for the 3D object prediction, while the precision, recall, and F1 for the relations prediction are 0.580).

Keywords: Annotation Dataset, Virtual Reality, Safety Training, Annotation Quality, Pre-Trained Models.

1. Introduction

Occupational safety remains a particular issue for the general industries due to the huge accidents that happened owing to unsafe behaviors and mechanical failures. Accidents in the construction industry are considered high compared with other industries [4], and more than 63,175 fire incidents have occurred in the United States in 2023 [3]. One of the most important technologies involved in safety training is virtual reality and augmented reality (AR) to enhance workers' safety skills. The manual development of VR scenarios for safety training remains limited in its ability to achieve high levels of realism [6] and ignores some of the critical factors involved in the accident reports [2]. To address these limitations, this study proposes an approach to create an annotated dataset from the real accident reports to train two pre-trained models, Bidirectional Encoder Representations from Transformers (BERT) for 3D object extraction and a DistilBERT-based model for relations extraction. The main objective of this research is to create an annotated dataset to train a deep learning model to extract important information that can be utilized in generating the VR safety training scenarios.

2. Dataset Quality Assessment

The dataset was annotated by a single expert annotator following detailed annotation guidelines. To ensure the corpus quality, several validation strategies were employed as the following:

2.1. Multi-Pass Annotation Process

Text annotated by humans is not accurate, so we need to apply the quality measurement technologies to ensure the reliability of annotated accident reports for use in NLP models. Intra-annotator agreement is the extent of a single annotator labeling the same text source across temporally separated periods [1]. The multi-pass quality shows that the number of identical labels is 7078, while the total number of labeled objects is 7322, and the number of correct relations is 8743 out of 8818 labeled relations, so the reliability is 96% for the labeled object and 99% for the labeled relations.

2.2. Manual Validation of Complex Cases

Despite careful annotation guidelines having been applied, annotation errors may still occur, as certain cases ranging from straightforward to highly complex can be subject to mislabeling these are typically classified as ambiguous instances [5]. The consistency validation process primarily focused on textual clarification of spatial relationships, including INSIDE, UNDER, and NEAR, and ambiguous entities, such as DIRECTION. In addition, particular attention was given to low-frequency entities and the action relations, and the results are presented in Table 1.

Table 1. Manual Validation Summary

Type	Validated	Valid	Revised	Removed
Entities	135	118	9	8
Relations	678	526	126	26
Total	**813**	**644**	**135**	**34**

2.3. Usability Evaluation of the Annotated Dataset

Pre-trained models were employed to evaluate the usability of the annotated dataset and ensure the efficiency of predicted 3D objects and relations, the BERT-base model to validate the predicted 3D objects and a DistilBERT-based model to validate the predicted relations. The results of usability tests based on the pre-trained models are an overall F1 of 0.77, a precision of 0.74, and a recall of 0.80 for the 3D object extraction, and 0.580 for the precision, recall, and F1 for the relation extraction.

3. Conclusion

The main contribution of this research is introducing the first 3D object-relation annotated dataset to automatically generate a VR safety training design. The annotated dataset provides richly annotated text pairs, covering twenty-eight key dimensions that can be represented in the VR scenarios. The evaluations of this dataset have been conducted by applying three testing procedures: reliability by multi-pass annotation, consistency by manual complex case validation, and usability by pre-trained models.

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