Photogrammetry-based VR Interactive Pedagogical Agent for K12 Education

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ABSTRACT

The effects of using various multimedia pedagogical agents with computer screens have been extensively studied in the past. However, two topics in this area of research remain relatively unexplored: the impact of virtual reality and of real-identity agents with high human likeness. The goal of my PhD project is to build and evaluate virtual reality agents that resemble well-known experts or role models in the learning content domain for K12 students. Three sub-systems necessary to build the pedagogical agent will be constructed and evaluated: speech synthesis, facial movement generation, and dialogue system. The different stages and the accompanying methodologies are outlined in this paper, including an overview of the deliverables.

CCS CONCEPTS

• Human-centered computing → Virtual reality; • Social and professional topics → K-12 education.

KEYWORDS

pedagogical agents, virtual reality, multimedia learning, learning effectiveness, text-to-speech

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1 INTRODUCTION

Multimedia pedagogical agents have been used as tools for education since the late 1990s [20, 24]. Many studies have evaluated how agent characteristics affect students' learning outcomes [3, 6, 22]. The most commonly evaluated agent features are (2D or 3D) format, appearance, voice, facial expressions and body gestures. Overall, the majority of the studies have focused on examining the effects of fictional agents presented on traditional computer screens in 2D or 3D formats. However, in the last decade, we have witnessed a rapid development of virtual reality (VR) solutions. VR—particularly the VR that includes the usage of head-mounted-displays (HMD) can provide users with the feeling of “being there” and thereby provide

potential benefits for learning. In particular, compared to conventional display, the feeling of presence provided by immersive VR could potentially remove physical limitations and let learners submerge in the virtual environment. Despite the fact that past studies have shown various benefits of using VR for learning, VR does not appear to be widely used for pedagogical agent research. Yet it could help the learner with more engagement and improve their cognitive skills [12] and it might be a good modality for learning abstract or conceptual knowledge, as well as procedural skill-related content [10].

Next to the VR solutions, another area of pedagogical agent research that remains relatively unexplored is the use of realistic-identity agents with high human likeness. To our knowledge, almost all studies on the usage of pedagogical agents choose for fictional agent roles instead of using real identify agents, for example, famous scientists or historical figures. The use of real-world characters could have a positive impact on learning due to the agent being perceived as an expert, as well as due to an increased engagement of the user triggered by the accompanying narrative. At this point, though, it is unclear what the learning effects are when using a VR agent with an authentic voice and appearance modelled after a real person who possesses expert authority or is viewed as a role model in the content field. Since recorded videos of real humans lack interactive features, speech synthesis and photogrammetry technology could be utilized to replicate a real person in VR. Therefore, the general aim of this project is to explore how a VR agent with high human likeness modelled on a real-world expert or a role model could help students' improve their learning gains.

2 MOTIVATION AND PROBLEM STATEMENT

In this PhD project, we will build and evaluate the effects of photogrammetry based VR pedagogical agents on K12 students' learning outcomes and motivation using existing learning materials and test questions. The objective is to improve learning gains by using realistic-looking and interactive VR agents that resemble well-known experts or role models in the learning content domains.

Thanks to the advances of text-to-speech (TTS), computer vision and natural language processing, it is now possible to synthesize a specific individual voice, create dynamic 3D facial movements and build interactive dialogue systems. Some of these technologies have been used in the past studies on pedagogical agents, for example, using generic voice from commercial TTS engine and synchronizing facial movements from speech. To the best of our knowledge there is however no study that has evaluated the effects of pedagogical agents that includes all these features, i.e., 1) an interactive dialogue VR agent that has the appearance of a role model 2) with generated facial movements from 3D photo scans and 3) synthesized speech

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replicating the original voice. Thus, to understand how such an agent affects K12 student learning outcomes, motivation and perception of the agent, we face the following challenges: training TTS models that could produce speech for desired voices, creating 3D facial movements with synchronization to speech using static neutral face photogrammetry scans, and integrating an agent dialogue system that can be adapted to certain learning content.

3 EXAMPLE USE CASE

The target use case for this research project is a VR pedagogical agent that would be used inside and outside of a classroom for K12 students. The idea of this implementation is to promote learning with the guidance of an expert (the VR agent) who is a known personality in the student's country. For example, an agent appears in an astronaut outfit with the face of a real astronaut's face. The objective is to build photo-realistic and interactive VR agents that look and sound like real experts or role models by using speech synthesis and photogrammetry technology.

4 RESEARCH QUESTIONS

Derived from motivation and problem statement in the previous section, this PhD project aims to answer the following research questions:

RQ1: *How do K12 students perceive photogrammetry-based VR interactive pedagogical agent with synthesized speech and dynamic facial animations?*

To answer this question, we aim to evaluate several different variables during the process of building a complete agent: the naturalness of the TTS and facial animations, the effects of agent identity, and the usability of the agent dialogue system.

RQ2: *How does the usage of this type of VR pedagogical agents affect K12 students' learning outcomes and motivation?*

Depending on the types of knowledge, treatment duration and frequency, the learning effects of using pedagogical agents could vary. Since we will use agents that are VR version well-known human experts or role models in the content domain, we expect the usage of this kind of agents will positively affect students' motivation. In order to test this assumption, we aim to compare the use of a VR agent to conventional classroom teaching.

5 RELATED WORK

In this section, we present a brief summary of related works about text-to-speech (TTS) systems, facial movement generation and dialogue systems.

5.1 TTS systems

Modern TTS systems are sequence-to-sequence architectures, which means that the inputs are text sentences and outputs are wave forms of speech. These systems have two main components: a feature prediction network and a vocoder network. The feature prediction network converts text embeddings into Mel-scale spectrograms, and the vocoder network produces time-domain waveforms using

Mel-scale spectrograms. A typical example of a modern TTS system is Tacotron 2 by Google [23]. The model appears to synthesize speech with a mean opinion score (MOS) of 4.53 out of 5, which is relatively high compared to the score for recorded human speech of 4.58. More recent studies on TTS systems have focused on synthesizing more natural and robust speech [15], training the model with limited amount of materials [5, 13], and synthesizing multilingual speech [18, 27]. However, studies [4] have pointed out that the style of the training material could affect the perceived naturalness of synthesized speech; for example, news speech materials are better than conversational and book speech. They also found that speech quality of TTS models that target replicating certain voices are overall better than the quality of voice conversion models that aim at producing different voice from the original speaker.

5.2 Facial movement generation

To generate facial movement for a realistic VR agent with a high likeness to an existing person, it is necessary to use rigging techniques to reconstruct the virtual face and generate facial expressions. There are generally two different approaches for face reconstruction, either using RGBD sensors (e.g., [2]) or using multi-camera arrays (e.g., [1]). In this study, we will use the photogrammetry method with multi-camera arrays to acquire a high-quality static face model. For dynamic facial animations, the common method is to use linear blendshape models [14]. To generate facial animations with this method, a set of FACS [7] blendshapes is required. However, acquiring the FACS blendshapes is not an easy task, since they are either constructed by scanning real human while displaying corresponding expressions or crafted manually. A more convenient method that emerged in recent years is to generate the expression blendshapes for the target face using existing sample facial rigs (e.g., [26]). The advantage of this method is that it only requires a neutral face scan as input.

5.3 Dialogue systems

Dialogue systems can be categorized as either task-oriented or open-domain, depending on their application purpose. Task-oriented systems deal with specific topics in a certain content domain (e.g., a ticket booking chatbot), while open-domain systems are usually designed to maximize user engagement [11]. For the purposes of our project, we will focus on task-oriented systems. Based on the architectures, we can further categorize task-oriented systems into the pipeline and end-to-end methods. The pipeline systems consist of four different modules: natural language understanding (NLU), dialogue state tracking (DST), dialogue policy and natural language generation (NLG). NLU converts the user's input into structured semantic representations, DST tracks the dialogue states with the user's current input and dialogue history, dialogue policy decides the system's next action based on the current dialogue state, and NLG produces the output in natural language according to the action policy [19]. The end-to-end system utilizes one neural model to perform input understanding and output generation at the same time. Both pipeline and end-to-end methods have their pros and cons. In pipeline methods, different modules are trained separately, the good performance of each module does not guarantee the whole system works well [8], and the training materials require annotated

datasets, which are human labour-intensive to construct. However, due to the separate module function design, pipeline systems are more transparent and controllable than just one neural model. The end-to-end methods could optimize the whole system as one unit, but require a large amount of training materials and difficult to check the underlining decisions.

6 RESEARCH PLAN AND METHODOLOGY

This PhD project is planned for 4 years (September, 2020 to September, 2024) with four stages. After a systematic literature review is conducted, 3 sub-systems for the agent will be built and tested one by one.

6.1 Stage 1: Systematic literature review

Before directly building the pedagogical agent, the first stage of this research would be conducting a systematic literature review about studies in the last decade that use agents for learning. The aims of the review are to: (1) Provide an overview of the design features for the agents and their impact on learning; (2) Collect technical information on how different agents are created with focus on audio and visual features; (3) Describe the experimental and contextual conditions used in past studies with pedagogical agents; and (4) Understand how past studies conducted evaluations of learning outcomes, learner motivation and agent perception. The results of the literature review will be used as a reference when we build and evaluate our agent.

6.2 Stage 2: Dutch TTS model

In the second stage of the research, we plan to train a Dutch TTS model for our desired use case. As a starting point, we will use the Tacotron 2 architecture since it has been implemented by many Python libraries. In the Tacotron 2 paper by Google [23], the quality of their synthesized speech was achieved by using an internal English dataset with around 25 hours of materials. From a practical perspective, it may be difficult to acquire 25 hours of high quality recorded speech by any given real-life personality. Thus, we would first use other Dutch speech materials to investigate what type of speech materials are best for training a TTS model and what the minimum amount of training material is needed for training a Dutch TTS model with acceptable quality. To evaluate the quality of synthesized speech, a user study will be conducted with our target population by examining the quality and perception of the custom voice. All user studies in the project will be conducted in line with our institutional ethical review board requirements and procedures.

6.3 Stage 3: Facial movement generation for the VR agent

Instead of developing a new model for facial movement generation with synchronization to speech, we plan to use available architectures that could be adapted to our project. So the first step in this stage would be investigating and comparing all up-to-date models that support 3D facial movement generation and emotional expressions in real-time using our training data. After evaluating the models for their quality and flexibility, we will then train the most

suitable model using the 3D scans of a neutral face. For the evaluation of this sub-system, we could first compare agents that using generated facial movements with real-human recorded videos, in both scenarios the voice would be the same real-human recorded speech. Then the Dutch TTS model developed in stage 2 will be integrated and we will examine how the target population perceives the agent, comparing recorded and synthesized modalities. If time allows, we will also consider adding body gestures since they can complement the information conveyed by facial expressions.

6.4 Stage 4: Agent dialogue system

Similar to the previous stage, we will also use readily available technology that could be modified and improved for the agent dialogue system. The dialogue system will be trained using materials for specific learning content and provide possibilities to be controlled by humans in specific exchanges. This is because most neural-network based dialogue systems are a “black box” – the process for generating conversations is not transparent and might lead to inappropriate responses to user requests. Thus, we will first evaluate which dialogue systems meet our requirements and then examine those features with a pre-test before integrating this sub-system into the agent. Finally, when the dialogue system is chosen and evaluated, we will combine all three sub-systems and conduct experiments on how the full VR pedagogical agent affects student learning outcomes and motivation.

7 COMPLETED AND PLANNED RESEARCH

As planned for the first stage of the research, a systematic literature review about using pedagogical agents in education has been conducted. The coding for each study about agent design characteristics, experiment contextual features and results evaluation has been completed. Preliminary results of the review provided a number of insights and helped us identify research gaps in the literature. Importantly, a clear majority of the existing studies provides outcomes for non-VR agents, with only a few studies examining the use of VR pedagogical agents (e.g., [9, 16, 21, 25]). Next to that, among all the studies included for the review, none of them used photogrammetry to build the agent. Most agents have the format of a 3D humanoid with a cartoon-like appearance. For studies that reported the usage and format of the speech, most of them chose to use recorded human speech instead of synthesized speech. All the studies with synthesized speech utilized available voices from their chosen TTS engine; no study created a custom voice for the agent. Interestingly, only one study evaluated the effects of using an agent that was modelled after a well-known person in the learning content domain [9]. The agent had the face resembling Neil Armstrong in an astronaut outfit while demonstrating the Apollo 11 mission. However, the voice of the agent was a generic one available from the TTS engine, rather than Neil Armstrong’s voice. Finally, there is an underrepresentation of studies that focus on the K12 population. Only 9% of our included studies that reported population age researched K12 students. The majority examined how pedagogical agents affect student learning at middle school or university level.

Apart from the systematic review, early experiments on training a Dutch TTS model have also been conducted. By training a Tacotron 2 model using 20 hours of audiobook materials, we have

verified that the chosen TTS architecture could indeed produce good quality Dutch speech. We used the following library for the Tacotron 2 architecture: Mozilla TTS [17]. We gained some first-hand experience of the conditions for good training materials. For example, 7 hours of training materials were not enough to train a decent quality model when using Tacotron 2. We also concluded that the speaker's voice for the training materials should have a neutral tone, minimal intonation and impersonation, and no mix of multiple languages.

Currently, we are finalizing the writing of the systematic literature review paper. For the next steps, we will first conduct more experiments to find out what the minimum required amount of material is that is required to train a decent quality Dutch TTS model. We plan to evaluate the quality of synthesized speech in September or October this year with our target population.

8 EXPECTED CONTRIBUTION

This proposed research project aims to contribute to the pedagogical agent field in the following ways:

Artifact contribution

- Building photogrammetry-based VR interactive agent with real identity using speech synthesis and dynamic facial animations.

Empirical contribution

- Evaluating the effects of using VR pedagogical agents for the under-representative population (K12 students) in the research field.
- Providing insights about how students perceive a photo-realistic VR agent with the identity of a well-known human expert or role model in the learning content domain.
- Examining the effects on learning and motivation when using a real-identity VR pedagogical agent.

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