Brush Up with AR: Supporting Children's Enjoyable Tooth-brushing through Augmented Reality Feedback

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***Abstract*—We developed an Augmented Reality (AR) application to enhance children's enjoyment during tooth-brushing sessions. Our application applies machine learning-based image classification techniques to recognize children's brushing motions. The application provides feedback to the user via AR effects that react positively or negatively based on whether the user shows appropriate brushing motion. In addition, our application contains a guidance video for children that demonstrates proper brushing methods and includes children's songs. Once brushing is complete, the child receives an entertaining animation reward. We evaluated the developed application with 11 children under the age of seven and conducted post-use interviews to assess its effectiveness in promoting an enjoyable brushing experience. Our findings indicate that children enjoyed using the application and felt more motivated to brush their teeth. We propose design guidelines for children's toothbrush applications based on these results. In the future, we plan to expand our research into oral health promotion applications that can encourage good brushing habits in children and contribute to their overall well-being.**

***Index Terms*—tooth brushing, augmented reality, children's oral care, children and technology, motion recognition, interaction design**

I. Introduction

Oral health is an essential consideration for the overall well-being of children [1]. Dental caries is a common ailment among children, with 60-90% of children worldwide being affected [2]. Brushing children's teeth at least twice a day with toothpaste is crucial for reducing the prevalence of tooth decay [3]. The American Dental Association recommends brushing teeth for at least two minutes to remove plaque effectively [4]. Chronic oral conditions generally manifest over a lifetime [5]. Thus, it is vital to manage dental health from early childhood.

Artificial Intelligence(AI) is capable of simulating and performing tasks that typically require human intelligence, such as logical reasoning, learning, and problem-solving [6]. AI technology can be applied in real-life scenarios to address various challenges [7]. Specifically, computer vision technology can detect human motion from static images or video sequences, which finds its application in several fields [8]. Furthermore, Augmented Reality(AR) blends the real and virtual worlds in real-time, providing users with an enhanced sense of immersion and realism [9].

Young children might struggle with visualizing objects in their minds. Therefore, a combination of physical and virtual environments can aid their understanding [10]. Young children grasp everything through play, becoming an essential part of their daily life [11]. Engaging and interactive learning is one of the potent elements that can create a high-participation learning environment [12]. Incorporating AR into learning content can increase satisfaction and enjoyment for young children, which may motivate them to engage more with the material [13].

Our study aims to facilitate an enjoyable tooth-brushing experience for young children and to motivate the establishment of consistent brushing habits. To achieve this goal, we developed an application that uses AI for the real-time recognition of brushing motions and provides real-time feedback through AR effects. The front camera of the smartphone captures the user's brushing motion. Machine learning-based image classification techniques are applied to determine the presence or absence of brushing motion. The application shows AR effect feedback according to the detected motion: positive feedback is displayed when a brushing motion is detected, and negative feedback is displayed when it is not. We added a guidance video as an extra feature that teaches proper brushing procedures, accompanied by melodies. Next, we had the children experience the finished application to see if we could get them to enjoy brushing.

The structure of this paper is as follows. Initially, we introduce related studies that inspired the design of our application. We then discuss the preliminary research conducted prior to the application's development and detail the design and user study of our initial prototype. Subsequently, we present the components of the main application and share the results of our experiments. Based on these results, we will explore potential design guidelines for a children's tooth-brushing assistance application and the expected impact of such guidelines. Finally, we outline future research directions based on this study.

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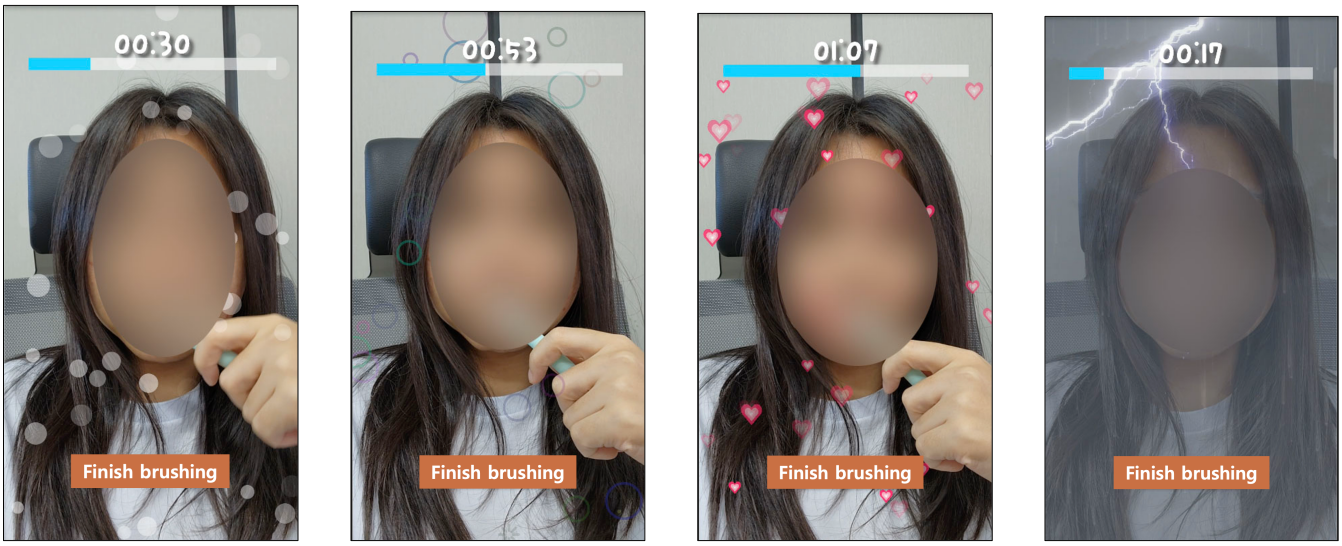


(a) White-bubbles effect (b) Color-bubbles effect (c) Hearts effect (d) Rain & Lightning effect

Fig. 1: Main application: The AR effect applied to AR camera

II. Related Work

A. Augmented Reality in Education

Researchers are actively conducting studies on the applications of AR in various fields. Dalim *et al.* developed an AR-based English teaching application targeting children for whom English is not their native language [14]. Their study confirmed that children enjoyed learning using the AR system. Syahidi *et al.* proposed an AR-assisted learning medium that uses 3D-based tracking and audio markers to help preschool children recognize animals and fruits alphabetically order in English [15]. They carried out a "Fun Testing" on their application. Escobedo *et al.* developed Mobis, a mobile-based Augmented Reality application, to improve the concentration of children with autism [16]. Their approach led to an increase in positive emotions and improved focus among the children.

B. Toothbrushing Application

Various studies have been conducted on applications designed to assist with tooth brushing. Shao *et al.* developed a tooth-brushing game for children and an accompanying application that allowed parents to monitor their activities [17]. Their findings showed that most children expressed enthusiasm for playing the tooth-brushing game. Parvin *et al.* developed a tooth-brushing system for children with autism using a home-based intelligent assistant and voice conversational agent [18]. Also, Zheng *et al.* developed a gamified tooth-brush coaching program for children with autism [19]. Lee *et al.* encouraged proper tooth brushing habits in children by showing the real-time effects of brushing on teeth through a physical avatar [20]. Kondo *et al.* proposed an AR tooth-brushing system that uses machine learning techniques to detect areas of teeth prone to contamination in real-time from PC camera footage [21]. By using AR effects to represent bacteria, the system promotes oral hygiene habits in children.

III. Initial Application Design and Evaluation

Before developing the main application, we implemented the core functionality of toothbrush motion detection and created a prototype application.

A. Tooth-brushing Motion Recognition Method

We employed machine learning image labeling techniques to recognize and categorize brushing motions. The model was crafted using Google's TensorFlow Lite Model Maker. The defined ImageClassifierDataLoader within this tool allows for transfer learning, ensuring a certain level of performance without the need for explicit neural network design. The model classifies brushing motions based on the position of the toothbrush as seen by the smartphone's front-facing camera, determining whether the child is brushing or not. The model consists of 3,416,867 parameters, and it achieved a classification accuracy of 75% during training. The training data was collected by extracting static images from videos of brushing motions, distinguishing between correct and incorrect brushing techniques. Each image was labeled 'Good' or 'Bad' based on the toothbrush's position. The ratio between training data and validation data was set at 90:10. After training with a subset of the training data, the validated model was saved in the .tflite format and incorporated into the application.

B. Prototype Interface

The initial prototype is an application for smartphones. The interface displays the camera feed across the entire screen. Two progress bars, indicating the duration of the brushing motion, are situated at the top of the screen. Below, a video guide for proper brushing techniques is presented (Fig.2).

Following the guidelines set by the American Dental Association, we have included a long progress bar that lasts 2 minutes and indicates the entire brushing period. We placed

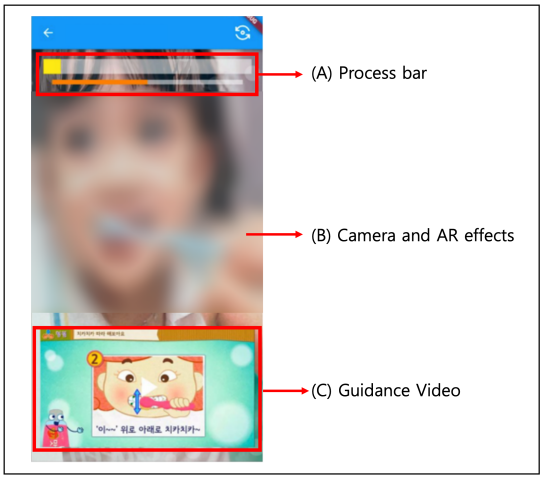


Fig. 2: Initial application: prototype interface

a short process bar below that, representing 10 seconds of brushing. The progress bar represents the length of brushing behavior classified by the Good label. The short progress bar fills up rapidly as the user motions, and we intended to give immediate feedback as the user motions.

When a child brushes their teeth in front of a smartphone's front-facing camera, three stages of AR effects are activated upon recognition of the brushing motion classified as 'Good'. In contrast, no particular AR effects are activated when the brushing motion is classified as 'Bad'.

C. Initial Evaluation

We conducted a user study to evaluate the initial prototype application. The study included three parent-child user groups (three parents, six children). Participants were observed by the researchers while experiencing the prototype brushing application, followed by an interview regarding the user experience.

The study results showed that most children tended to focus more on the brushing guidance video than on the AR effects. Most participants reported brushing while using the application more intriguing than the conventional brushing method while looking in a mirror. Once start using the application, none of the children resisted or avoided brushing, indicating a heightened level of engagement in their brushing activity.

However, some mentioned the inconvenience due to the accuracy of motion recognition. Despite children's consistent brushing motions, the system often misclassified them as not brushing. This misclassification led to an incorrect calculation of the total brushing time, causing it to be excessively prolonged, which became a source of inconvenience.

IV. MAIN APPLICATION AND FEATURES

We modified the main application considering the observation from the initial prototype that children paid more attention to the guidance video than to the AR effect while brushing. The content was split into a *guidance video* and *AR camera* to address this issue, resulting in separate sections in the application.

A. Guidance video

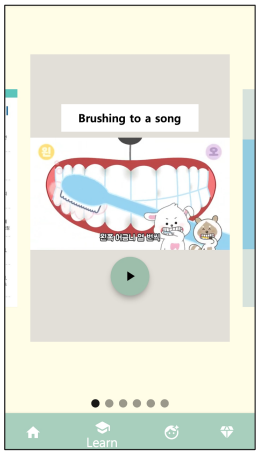


Fig. 3: Main application: guidance video

The *guidance video* (Fig.3), accompanied by a nursery rhyme, lasts approximately 3 minutes. Moreover, the video features lovable characters that are likely to connect with children, stimulating their interest and encouraging a cheerful commitment to the brushing. This *guidance video* is crafted to engage children, integrating captivating lyrics and scenes. Notably, its length exceeds the commonly recommended tooth-brushing duration of 2 minutes. For example, it incorporates rhythmic lyrics set to tunes, such as "Round and round on the right tooth".

B. AR Camera

The *AR camera* (Fig.1) uses machine learning image classification techniques to classify the brushing motion, which is the same model as the initial prototype. Use the front camera to capture the user's brushing motion and display a positive or negative AR feedback effect based on their motions.

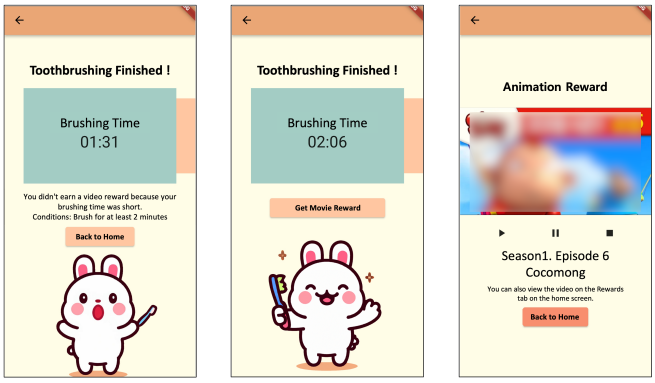
Positive feedback is triggered when the brushing action is classified as brushing when labeled as 'Good' and is structured in three stages. Based on the cumulative duration of the 'Good' label:

- From 0 to 30 seconds, the 1st stage, the "White-bubbles effect" is displayed (Fig.1a).
- From 30 to 60 seconds, the 2nd stage, the "Color-bubbles effect" is shown (Fig.1b).
- When the duration surpasses 60 seconds, the 3rd stage, the "Hearts effect" is applied (Fig.1c).

Negative feedback is applied when the action is not classified as brushing when labeled as 'Bad'. In such cases, the "Rain & Lightning effect" is displayed as the AR effect (Fig.1d).

A progress bar on the screen shows the duration of up to 2 minutes for brushing. The system measures brushing time from the moment users access the *AR camera* screen until they press the 'Finish brushing' button. Users can press the 'Finish brushing' button anytime, but they will only receive animation rewards if they brush for 2 minutes.

C. Animation reward



(a) Failed to receive animation reward (b) Received animation reward (c) Animation reward viewing

Fig. 4: Main application: results screen after tooth-brushing and animation reward

The user does not receive an *animation reward* if the brushing time is less than 2 minutes (Fig.4a). However, they do receive an *animation reward* if the brushing time exceeds 2 minutes (Fig.4b). The animation reward provided lasts for about 10 to 15 minutes, and a new video is presented every time (Fig.4c).

V. Experiment

We conducted an experiment with 11 children under the age of 7 to evaluate the effectiveness of the main application. During their regular brushing routine, the children, with assistance and observation from their parents, brushed their teeth using the *guidance video* and *AR camera*. Following the experiment, we interviewed both the parents and the children.

VI. Results

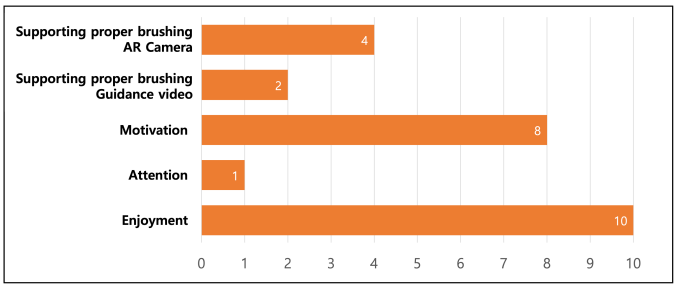


Fig. 5: Number of users evaluated on positive effects of the application

We analyzed the interviews to evaluate our application, and the results are presented in Fig. 5. According to the analysis of the interview results, the participants expressed that our application positively impacted helping children brush their teeth. Four participants reported that the *AR camera* was helpful when parents watched their children using the application and were asked about its support for proper brushing. Two participants found the *guidance video* beneficial. Eight participants reported the app motivating when asked about its influence on their children's motivation. One parent mentioned that the application helped her child pay attention while brushing. Ten of the eleven participating children reported experiencing enjoyment while brushing using the application. Comparing preferences between the *guidance video* and the *AR camera*, six participants preferred the *guidance video*, while four favored the *AR camera*. One participant did not respond. Among children 5 years old and younger, four out of six preferred the *guidance video*, while among those older than 6, three out of five tended to prefer the *AR camera*.

Nevertheless, some concerns were raised about specific features of the application and potential side effects. Some of the participants reported that the smartphone screen was too small for them to watch while brushing. Moreover, the AR feedback caused confusion in some situations because the AR did not correctly identify the brushing motions. Participants suggested improvements to the AR effect, such as portraying the gradual cleaning of teeth or the disappearance of bacteria for added educational value for children. Some children, while watching the *guidance video*, became solely focused on the content and momentarily stopped brushing. Typically, children used the application in front of bathroom sinks, but a few used it in other locations, like the living room. Most children required a guardian's assistance to conclude the brushing session. Only one parent was in favor of offering a animation reward for brushing. A side effect emerged as children watched the reward video repeatedly.

VII. Design Guidelines

We propose design guidelines for an application that assists children in brushing their teeth.

A. Device for Installing Proper Tooth-brushing and Accurate Motion Recognition

Encouraging behavior in front of a bathroom sink is crucial to ensuring proper tooth brushing. To guide users to the sink for brushing, installed devices within the bathroom can be used instead of handheld devices like smartphones. Additionally, a larger display should be utilized for user convenience. Presenting a face guideline on the screen at the start of the application can guide the user into the correct position in the screen, which in turn increases the action recognition rates. Therefore, we could expect an increased convenience and promotion in proper tooth-brushing habits.

B. Application of AR Effects Related to Tooth-brushing

Although our application's AR effects successfully attracted children's attention to brushing actions by enhancing their understanding of positive and negative outcomes, guardians desired to achieve an additional educational effect with them. Visual representations of teeth getting progressively cleaner during brushing or bacteria multiplying when not brushing could help children understand the advantages and consequences of their brushing motions.

C. Interaction Methods Tailored to User Characteristics

We found that user engagement levels varied by age and content. Children under the age of 5 preferred the *guidance video*, which allows them to brush their teeth while listening to songs, whereas those aged 6 and above were interested in the *AR camera*, which provides feedback based on their actions. According to Piaget and Cook, symbolic thinking develops in children aged 2-7 during the preoperational stage, which means when they see a behavioral model, it is remembered and easy to be mimicked later on [22]. Furthermore, previous research indicates that children can only effectively brush their teeth independently once they are at least 6 years old [23].

Therefore, to maximize user engagement, it is recommended to provide various forms of interaction for different age categories. For children under five, providing voice guidance utilizing an AR avatar to describe each brushing step can be a beneficial method. For children ages six and above, providing essential brushing guidelines, together with AR effects that change based on their motions, is an effective way to help them brush their teeth autonomously.

D. Incorporating Parental Involvement for Enhanced External Support

For children's oral hygiene, it is imperative to have parental or guardian supervision when brushing teeth until around the age of 8 [1]. Our application did not explicitly include the process where parents assist in wrapping up the tooth brushing session. Incorporating a segment in the application where parents can assist their children would be beneficial. For instance, the application could display more dramatic AR effects when the child receives assistance from their parents after finishing brushing their teeth. This feature could encourage children to complete their brushing routine effectively and motivate parents to participate in the process.

E. Notification System for Preventing Over-Engagement

When users become too engaged in the guidance videos or AR effects in the *AR camera*, they may stop brushing their teeth. To prevent this drop in engagement, a supportive design feature is necessary. For example, if the user stops brushing their teeth, the system could display a prompt that says, "Please keep brushing your teeth". Since younger children may find it difficult to read, providing this reminder through voice notifications or a visual guidance is desired.

F. Immediate and Accumulating Reward

Offering animated videos as a reward to children upon completion of brushing can lead to an unintended side effect; the children might become overly immersed in the video, overshadowing the primary brushing activity. Also, such a reward does not motivate the children toward the next brushing period. Therefore, immediately gratifying, yet accumulating rewards toward a greater goal is required. For example:

- Puzzle Pieces: After each brushing session, children can earn a puzzle piece. Over time, as they accumulate these pieces, they can eventually complete a whole puzzle. This can give them a sense of achievement and motivation over brushing sessions.
- Character Stickers: Provide stickers of various characters for them to collect. As children continue their good brushing habits, they can work towards completing a whole set or series of stickers. This offers both instant gratification and a longer-term collecting goal.

Such types of rewards provide both immediate sense of achievement as well as an expectation toward next goal, potentially supporting in forming consistent brushing habits.

VIII. CONCLUSION AND FUTURE WORK

In this study, we developed an AR-based application to assist children with brushing their teeth and conducted a user study to evaluate its effectiveness through interviews. The results confirmed that the application contributed to making tooth brushing more enjoyable for children and that the AR feedback has the potential to motivate children in their brushing habits. On the other hand, some issues were raised concerning the device size being too small, recognition errors related to the brushing motion, and unintended side effects of animation video rewards. These insights not only highlighted the challenges we faced but also provided valuable directions for refining our approach.

Based on these findings, we proposed design guidelines applicable to children's tooth-brushing assistance applications. Our proposed guidelines emphasize the significance of a device setup that promotes correct tooth-brushing habits and ensures accurate motion recognition. Balancing engagement and educational content of AR effects is also important. Recognizing the varied needs of users, especially by age, interaction methods should be tailored accordingly. The crucial role of parental involvement in a child's brushing routine is highlighted, suggesting features that foster parental participation. Maintaining user engagement remains a challenge, underscoring the need for a notification system that redirects focus back to brushing when distractions occur. Lastly, an effective reward system should offer immediate gratification, but rewards shouldn't be so excessive that they outweigh the importance of the brushing activity. This ensures that children remain motivated to brush their teeth without becoming overly immersed in disproportionate rewards.

Based on our current study results, we expect to extend the study to a large-scale experiment to verify the application's effectiveness at a statistically significant level. Lastly, we plan to extend this research in a direction that can contribute more significantly to improving children's oral hygiene. We anticipate this will further contribute to fostering healthy habits in children.

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