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Evaluating Toothbrushing Performance in Support of Practical Ubiquitous Healthcare

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1. Abstract

Ubiquitous computing has become a part of our daily lives, with people around the world carrying devices such as smartphones and smartwatches on their persons every day. These devices have a number of sensors that enable us to collect data about these users that gives us a great deal of insight into their lives. We can observe a user's daily routines by analyzing GPS data, observe a user's exercise routine by analyzing accelerometer data, and even evaluate how well they perform certain activities by analyzing audio data. One of the most important applications of the analysis of this data is its use in ubiquitous healthcare. Using ubiquitous computing, caregivers can collect reliable long-term data on their patients' daily-life activities that gives insights into the patients' health and ability to live independently. Using this data, caregivers can increase the quality of care given to the patients and can also significantly reduce the cost of care.

One important way in which this data can be used is through the qualitative analysis of daily-life activities, allowing caregivers to analyze the patient's performance at specific activities. The uses for this type of analysis may vary depending on the patient, e.g., a patient with diabetes may need to be evaluated while standing still to monitor for a degrading ability to maintain their balance, while a patient with Parkinson's disease may need to be monitored during daily activities for symptoms such as shaking and stiffness of movement. However, this type of analysis is not limited to patients with a specific disease. A good example of an activity that requires this type of analysis for all patients is toothbrushing.

Toothbrushing is an activity that everyone should conduct multiple times per day, that requires proper technique to be effective, and that generally is done poorly. Given this general applicability of toothbrushing evaluation to the average patient, our work focuses on supporting ubiquitous healthcare by providing methods for automated toothbrushing evaluation. Using ubiquitous computing to automate the evaluation of such a daily-life activity is important, since conducting this type of detailed evaluation would otherwise require direct interaction between patients and specialists on a regular basis, which can be extremely costly and impractical for most patients.

In our work, we address some of the key issues that are faced when attempting to perform a qualitative analysis of a person's toothbrushing. First, this type of analysis can place an increased burden on the patients by requiring them to purchase specialized sensors to collect the data needed for the evaluation, e.g., by requiring patients to purchase specialized toothbrushes in order to analyze their toothbrushing. Second, enabling this level of support can place a large burden on experts and researchers, as these systems are typically handcrafted for a specific activity, requiring a large effort to design and train. We address each of these challenges in our pursuit of ubiquitous healthcare that is accessible to patients at low cost and with low burden.

We first address the need for specialized sensors by using only audio data collected by a commodity smartphone when evaluating toothbrushing performance. Our method starts by conducting activity recognition on the recorded audio to classify segments of audio into several classes that correspond to what part of the mouth the user is brushing and what type of brush stroke they are using. We then provide users with feedback on their brushing performance by estimating how well they brushed based on how long they spent brushing different areas of their mouth and the type of brush stroke used. We next address the burden placed on researchers in our work on applying deep learning to performance evaluation in order to automate feature extraction processes. We exploit the ability of deep neural networks to automatically extract meaningful features from data to conduct performance evaluation using raw sensor data as input. By doing so, we remove the need to develop handcrafted features for the data and make it easier for researchers to process larger datasets when training their evaluation models.

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