Interactive Video Acquisition and Learning System for Motor Assessment of Parkinson's Disease

Yunyue Wei, **Bingquan Zhu**, **Chen Hou**, **Chen Zhang** and **Yanan Sui**
National Engineering Laboratory for Neuromodulation, SAE, Tsinghua University
{weiyy20, zhubq17, hou-c17}@mails.tsinghua.edu.cn, {zhangchen2020, ysui}@tsinghua.edu.cn

Abstract

Diagnosis and treatment for Parkinson's disease rely on the evaluation of motor functions, which is expensive and time consuming when performing at clinics. It is also difficult for patients to record correct movements at home without the guidance from experienced physicians. To help patients with Parkinson's disease get better evaluation from in-home recorded movement videos, we developed an interactive video acquisition and learning system for clinical motor assessments. The system provides real-time guidance with multi-level body keypoint tracking and analysis to patients, which guarantees correct understanding and performing of clinical tasks. We tested its effectiveness on healthy subjects, and the efficiency and usability on patient groups. Experiments showed that our system enabled high quality video recordings following clinical standards, benefiting both patients and physicians. Our system provides a novel learning-based telemedicine approach for the care of patients with Parkinson's disease.

1 Introduction

Parkinson's Disease (PD) is a prevalent neurodegenerative disease that impairs motor functions. The diagnosis and treatment of PD heavily rely on regular motor examinations at clinics. It is cost- and time-consuming to patients, while the routine evaluation processes are repetitive and time-consuming to physicians.

Telemedicine may provide a promising solution for more accessible movement assessments. It overcomes geographical barriers and links medical providers to patients online [Wootton, 2001; Perednia and Allen, 1995]. Mobile app is an affordable and efficient approach for telemedicine. Symptoms of PD have been assessed on smartphones by accelerometer [Zhan *et al.*, 2018], by self-rating[Bot *et al.*, 2016] and by screen drawing task [Kuosmanen *et al.*, 2020; Tian *et al.*, 2019]. Advanced machine learning techniques could facilitate primary diagnoses and greatly reduce clinician's workload, such as automatic speech performance rating [Nilashi *et al.*, 2018; Tsanas, 2012].

Most of the clinical motor assessment tasks from the Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS) Part III [Goetz *et al.*, 2008] could be video captured with the help of an interactive system in the absence of physicians. However, out-of-clinic recording of MDS-UPDRS tests has two main challenges: 1) incorrect movements without professional guidance (due to misunderstanding); 2) poor video quality (dim light or missing body parts from view). Meanwhile, no MDS-UPDRS video datasets are publicly available to promote real applicable machine learning algorithms for automatic diagnosis of PD. A scalable video acquisition system could significantly boost data collection, benefiting both research and clinical practice. To the best of our knowledge, interactively capturing standard MDS-UPDRS videos using smartphone is still a missing part. A specialized mobile app for high quality remote video collection and analysis is in great need for telemedicine of Parkinson's disease.

We developed PD-GUIDER, an interactive video acquisition and learning system for in-home motor assessments of PD[1]. It is the first mobile app for movement recording of standard MDS-UPDRS motor assessments. Our AI engine provides real-time guidance to patients to guarantee correct movement and efficient recording. We tested the effectiveness of the system on healthy subjects and evaluated its performance on patients with Parkinson's disease. High quality videos of standard movement tasks can be easily recorded by patient using PD-GUIDER. We present an efficient telemedicine system equiped with AI engine for motor assessment of Parkinson's disease.

2 System Architecture

The workflow of PD-GUIDER is illustrated in Figure 1. To ensure correct movements, the app shows video demonstrations before each assessment and provides audio instructions. Interactive calibration with audio guidance and on-screen bounding boxes indicating body positions is integrated in the system. Body-keypoint-based auto-recording, one-click-upload and selfie mode (for individual recording without help, see Fig 2) features further simplify user operations. Hand keypoint detection algorithm provides primary analysis such as finger tap counting. In this way, video collection for

[1]https://youtu.be/f3iIioA5wI4

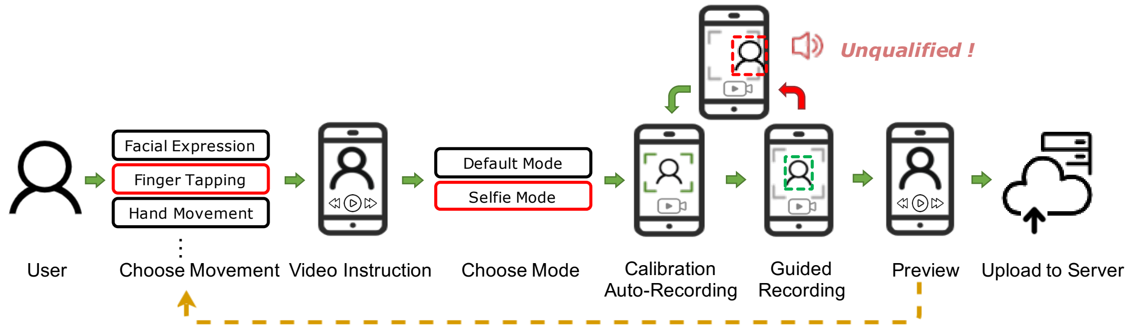

Figure 1: **System Workflow.** The green arrows indicate the procedure for video acquisition. The red arrow indicates the correction step for unqualified video recording. The dashed yellow arrow indicates choosing another movement task after recording, which is optional.

motor examination for patients with PD and preliminary motor function analysis are streamlined and standardized using PD-GUIDER.

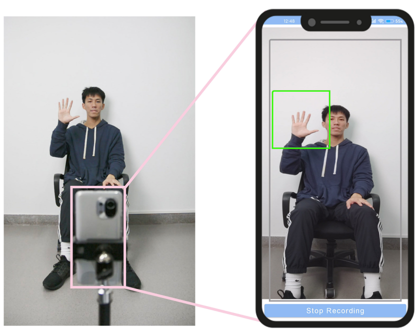

Figure 2: Finger tapping task in selfie mode.

3 AI Engine

Deep learning models work as AI engines to drive PD-GUIDER (see Figure 3). Camera calibration and recording guidance are based on real-time monitoring of user movements. We embedded PD-GUIDER with two pre-trained pose estimation models: *PoseNet* [Bazarevsky *et al.*, 2020] and *HandPose* [Zhang *et al.*, 2020]. *PoseNet* and *HandPose* estimate body and hand poses from video frames. We implemented the models with TensorFlow Lite [Google Inc.] to run PD-GUIDER on smartphones and infer user movements. The whole system runs fluently on ordinary Android devices.

3.1 Real-time Calibration

Dim environment and moving out of camera are common problems in out-of-clinic recordings, which greatly hinder diagnosis and research. To ensure high-quality recording, we developed real-time calibration. PD-GUIDER detects environmental luminance by computing frame pixel values of background area. On the meantime, it performs ”hard calibration”, checking if body bounding box (determined by *PoseNet* detected body keypoint positions) falls inside movement boundary box (preset positions) frame-by-frame. The system displays the boxes in green and grey respectively. Video recording cannot start or would stop if dim environment or wrong body position occurs(see Figure 4 (a) (b)).

To assist users, a preset silhouette presents on the screen (see Figure 4 (a)). It acts as ”soft calibration”: aligning head within the silhouette ensures proper recording position. With both ”soft calibration” and ”hard calibration”, users are able to self-calibrate smoothly.

Movement boundary box positions vary with different tests. For example, as the out-of-camera problem is common in gait assessment, PD-GUIDER calibrates with a small boundary box to ensure sufficient walking distance, and then changes the boundary box to full frame size as recording begins. For posture assessment (user stands still in front of camera) that is almost motionless, PD-GUIDER sets large boundary box and silhouette for clearer view of the body.

3.2 Movement Analysis and Interactive Guidance

During recording, PD-GUIDER provides audio guidance to users to perform correct movements, and inform the end of recording. Basic analysis from detected keypoints provides preliminary information about the movement. We included *preset guidance* for all 12 movement tasks as user instructions, and additional *video-based guidance* for the four error-prone tests (see below). Note that calibration function always runs in the backend to guarantee proper body position.

Preset Audio Instructions. The system plays preset audios to guide user movement performance step-by-step when recording begins. It alleviates the memory load for patients with PD who may suffer from cognitive impairments. Audio instructions could also distract patients from intentionally controlling their symptoms such as tremor.

Real-Time Guidance for Movements. Besides preset audios, we designed task-specific real-time guidance to better assist users. Inspired by state machine, the system recognizes user movements from detected body/hand keypoints, and guides user to target state in time.

For finger tapping task and hand movement task, PD-GUIDER would draw a *hand box* near the user’s shoulder given body keypoints from *PoseNet*. Users are instructed to raise hand to the corresponding hand box. Instead of predicting from the entire frame, the *HandPose* model infers hand keypoints from the hand box area to improve accuracy. The

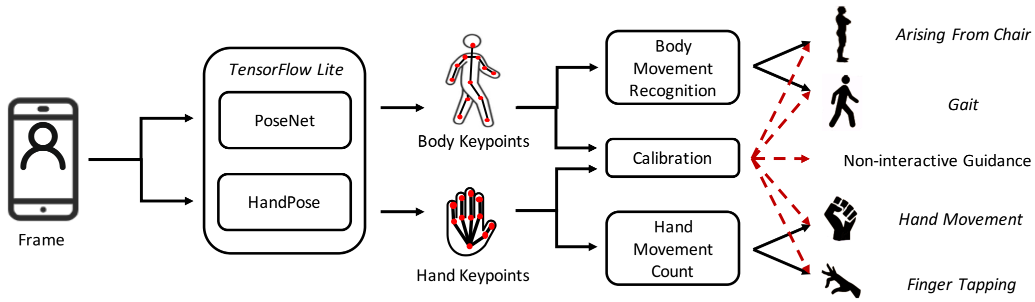

Figure 3: **AI Engines.** Keypoint estimation supports real-time calibration, movement recognition and interactive guidance.

system recognizes finger tapping or hand open-close behavior by hand keypoint positions and counts movement repeat numbers to determine the end of task. (see Figure 2)

For arising-from-chair task, camera calibration makes enough space for standing by inferring standing position from seated user. Then PD-GUIDER guide user to stand up with arm crossed before chest (if unsuccessful, push off using the chair arms). As user stands steadily, it gives sit-down instruction and automatically ends recording after the user is seated.

For gait task (in which user walks toward camera, turns around and returns to the armchair), calibration process is similar to the arising-from-chair task. Since it is hard for user to determine the turning point during walking, PD-GUIDER monitors user's body box size and guide him/her to turn around when the body box reaches preset threshold. As user sits steadily, the recording ends.

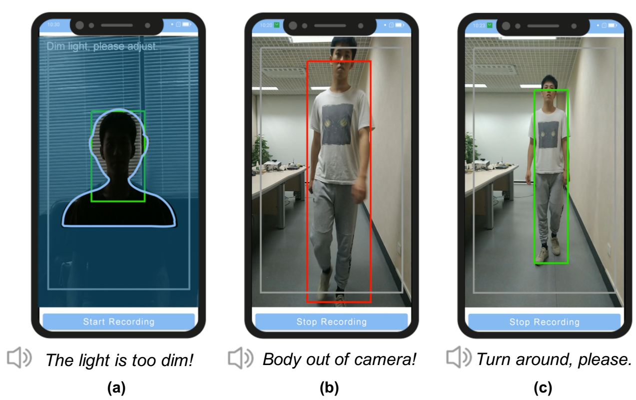

Figure 4: **Interactive Guidance.** (a) Alert of dim environment background in calibration. (b) Alert of out-of-camera error in gait task. (c) Instruction of turning in gait task.

4 Evaluation

We evaluated three aspects of PD-GUIDER : the guidance *efficacy* and the app *usability* rated by users, and the video *quality* examined by experts. Five healthy subjects used the app and confirmed that it functioned normally. We recruited 21 patients with PD to record MDS-UPDRS movement assessment and divided them into two groups: 10 patients used PD-GUIDER (*with app group*), and the rest didn't (*without app group*). The *with app group* showed improved efficacy compared to the *without app group*: lowered movement error rate (proportion of videos with wrong movements; with app: 9.3%, without app: 16.7%), and shortened total recording time (with app: 34 minutes, without app: 57 minutes; group average; statistically significant). The PD-GUIDER users rated the app with high usability (7 rated useful or very useful, 3 rated neutral; all rated helpful or very helpful). Two experts approved that PD-GUIDER improved video quality, and the proportion of videos missing critical body parts fell below 2% (with app) from above 50% (without app). PD-GUIDER also successfully guided PD patients with cognitive problems.

5 Conclusion

We proposed PD-GUIDER, an interactive video acquisition and learning system to assist motor assessments for PD patients with high efficiency and high quality. We implemented cutting-edge computer vision and machine learning techniques into the mobile app to guide, record, and analyze movement videos of clinical motor examinations. AI-based calibration and interactive procedure ensured video quality and the clinical value of recordings.

Preliminary experiment demonstrated the potential of PD-GUIDER as an efficient AI-based telemedicine approach for Parkinson's disease. Collecting high-quality and diagnostic-level videos in large-scale becomes feasible with this system. Currently, our system is limited to single person analysis. To facilitate patients who need assistance in certain tasks such as gait, we would implement multi-person tracking and analyzing tools. PD-GUIDER could be easily modified and applied to speech assessments of PD [Fang *et al.*, 2020] and motor examinations of other movement disorders. Video de-identification methods [Zhu *et al.*, 2020] can be applied for privacy protection concerns. Automatic rating and symptom analysis would further benefit patients with diagnostic suggestions and long-term monitoring in the future.

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