Customizing Physiotherapy Games tailored to Parkinson's Disease

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***Abstract*—Recent technological advances have made it possible to develop serious games in augmented or virtual reality settings with the aid of sensors such as Microsoft's Kinect. Such games are meant to augment and not replace physiotherapy sessions and allow patients to exercise in front of a large TV monitor. In this paper we discuss ways to enable customization in PD-oriented serious games using the example of "driving" an automobile on a road with alternating turns, straight paths, traffic lights, etc. The particular succession of these prefabs can be tailored by an attending physiotherapist to offer the intended rehabilitation opportunities to a given patient. This ability for parametrization is very important for PD, as it allows tailoring of a game to a patient not only in the first few establishing physiotherapy sessions, but also as medium-term gains from exercise or medication are realized or even as the disease progresses. For example, based on the particular motor dexterities of a given patient, the roadway can be dynamically generated based on past and current performance data. Finally, we discuss how to "map" PD specific physiotherapy exercises onto car controlling activities such as accelerating, breaking and turning.**

Keywords—Parkinson's Disease; Physiotherapy; Microsoft Kinect; Unity3D game engine.

I. Introduction

Parkinson's disease (PD) is named after James Parkinson, the first who recorded and reported the symptoms. The ailment is caused by the destruction of dopamine-producing neurons the mid-brain area called "substantia nigra", a region where body control is based. It is so far unknown why these cells are lost, and PD remains untreatable [1]. According to the European Parkinson's Disease Association (EPDA) [2], around 6.3 million people suffer from the disease worldwide. Symptoms progress slowly but irreversibly, so that late stages are more abundant in the elderly (>60 year old) population, while only approximately 10% of PD patients are under 50 years old. In early stages PD commonly affects motor function, whereas in later stages patients typically suffer from cognitive, behavioral and mental-related symptoms [3]. Additional non motor-related symptoms may include sleep disturbances, depression, anxiety, psychosis and visual hallucinations, cognitive impairment, pain and fatigue.

In addition, four distinct, fundamental non-motor symptoms can be grouped under the acronym TRAP: Tremor, Rigidity, Akinesia (or bradykinesia) and Postural instability [4]. Any of these symptoms hinders common daily activities and troubles patients' social relationships, thus reducing the quality of life, especially as the disease progresses [5], [6]. Tremor can be distinguished in tremor at rest and postural tremor. Tremor at rest is the most ordinary symptom, appearing at some point during the disease among the 75% of the patients [7], making it the most distinctive and easily recognized sign of the disease. It is described as an unintentional and rhythmic movement of body parts (limps, head, and face sections) while relaxed. Meanwhile postural tremor, associated with body movement (e.g. walking) or a controlled still posture (e.g., standing) can easily be misdiagnosed as essential tremor in the absence of other symptoms [8].

Rigidity, on the other hand, describes the inability of limb muscles to relax, providing high resistance during passive movement of the limb, the reason why it is also called cogwheel phenomenon. In more advanced stages, the muscles of those limbs can be described as stiff and highly inflexible. PD patients may also suffer from pain due to the rigidity, such as 'painful shoulder', one of the trait characteristics for PD [4].

Akinesia (or bradykinesia), one of the three main signs of the PD condition [2], refers to the slowness of patients in carrying out a voluntary movement, rather than initiating one. Akinesia can be present to the 78-98% of PD patients [8] and troubles them during the entire course of the disease. To detect akinesia, PD patients are usually asked to repeatedly perform rapid movements. Finally, Postural Instability expresses the lack of postural reflexes during standing, walking or interacting with objects in space [9] and is usually absent in the early stages of PD. The symptom depends on the severity and course of the disease [10] and is highly correlated to the frequency of patients' falls. Postural instability and akinesia can be an especially dangerous combination and one which can lead to severe injuries.

Although so far a cure for PD has not been found, medication usually helps contain the symptoms and maintain body functionality at reasonable levels through the lifetime of the patient. According to information provided by the American Parkinson Disease Association (APDA) [11] six categories of drugs are proposed for PD condition therapy: levodopa, dopamine agonists, MAO-B inhibitors, COMT inhibitor and levodopa, anticholinergic agents and amantadine.

In addition to drug-based treatment, physiotherapy appears highly effective in reducing and even containing PD-related symptoms. A number of Parkinson clinical facilities and associations provide physical activity guidelines, suggesting daily activities and tasks, even diet schedules. For example the Parkinson Society of Canada provides online detailed instructions on how to correctly perform stretching and other physical exercises [14]. Randomized controlled trials, e.g., [15], support that physical exercise such as stretching, aerobics, unweighted or weighed treadmill and strength training improves motor functionality (leg stretching, muscle strength, balance and walking) and the quality of life. A training program conducted in the patients' homes instead of a clinical facility used exercises tailored to the condition of each patient [16] with weekly visits by a physiotherapist. Participants kept a record of falls, the analysis of which revealed lower fall rates for patients that followed home-based exercise programs with detailed preparation and documentation compared to those who did not. These results are corroborated by a different study [17] which employed experimental balance training including self-destabilization exercises, externally-forced destabilization exercises and coordination of leg and hands during walking. These exercises improved postural stability and boosted patients' confidence as a result of the reduced frequency of falls. In fact, the benefits in postural stability as a result of that exercise program were maintained for at least one month after the end of sessions.

Additional benefits resulting from home-based rehabilitation include significant cuts in treatment costs. Indeed, PD patients must frequently attend physiotherapy sessions to either notice an improvement or maintain the gains from clinical rehabilitation programs [18]. The effectiveness of home-based, structured physical therapy exercise programs tailored to the individual patient is also supported elsewhere [19] and is corroborated by measurable improvements in motor capability.

II. A RACING GAME TAILORED TO PARKINSON'S DISEASE

The present paper reports on components of a goal-oriented serious game for PD patients in a playful virtual environment as an alternative to following a predetermined rehabilitation program. Patients following a long-term repetitive exercise schedule can easily get bored, lose interest and eventually drop out of a rehabilitation program (e.g., [20] and [21]). Exergames on the other hand engage patients into repeatedly executing simple or complex exercise patterns within a goal-oriented enjoyable context, with real-time feedback and rewards along the way using visual and auditory cues.

We have thus been implementing a serious game targeting PD patients with mild symptoms (using Part III of UPDRS modified scale of MDS [22]), i.e., without severe postural instabilities and motor impairments. Our solution employs Microsoft Kinect, an off-the-shelf solution that can easily be installed in both clinical and home environments to provide affordable motion capture. The Kinect sensor provides data streams from an RGB and an IR depth camera. The MS Kinect SDK processes the depth-map obtain in each frame to yield the 3D skeleton of a human in front of it in real time. When the player's movements "match" gestures programmed in a particular game, a 3D cartoon avatar of a driver in a sports car moves accordingly in the game environment.

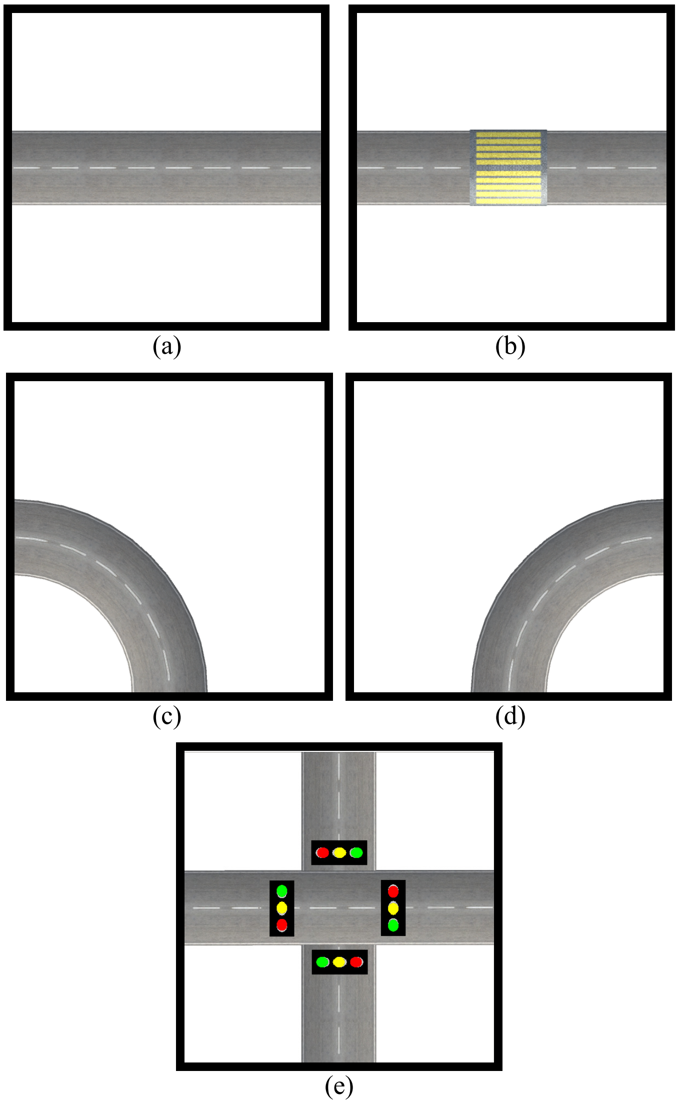

Fig. 1: Fundamental unit road elements to be used by the path generator based on rules derived from the individual rehabilitation needs of a given patient: (a) straight road segment, (b) straight road segment with a zebra crossing, (c, d) left and right turn, respectively and (e) a road crossing with traffic lights.

The allowed body moving patterns are based on published training programs (e.g., [23]), have been adapted to PD patients (as in e.g., [24]) and adhere to design principles appropriate for the PD condition [25]. These gestures were designed to improve postural stability and reflexes as well as increase overall mobility of upper & lower limbs. Game-embedded decision making is intended to improve the player's cognitive reaction. This agrees with [26] which advocates fast decision making combined with (depending on the level of the game) big but slow and fluent movements. Finally, the Unity game engine, a powerful development platform used to develop 2D & 3D games, was used to create proper gaming virtual environments with artefacts users can interact with.

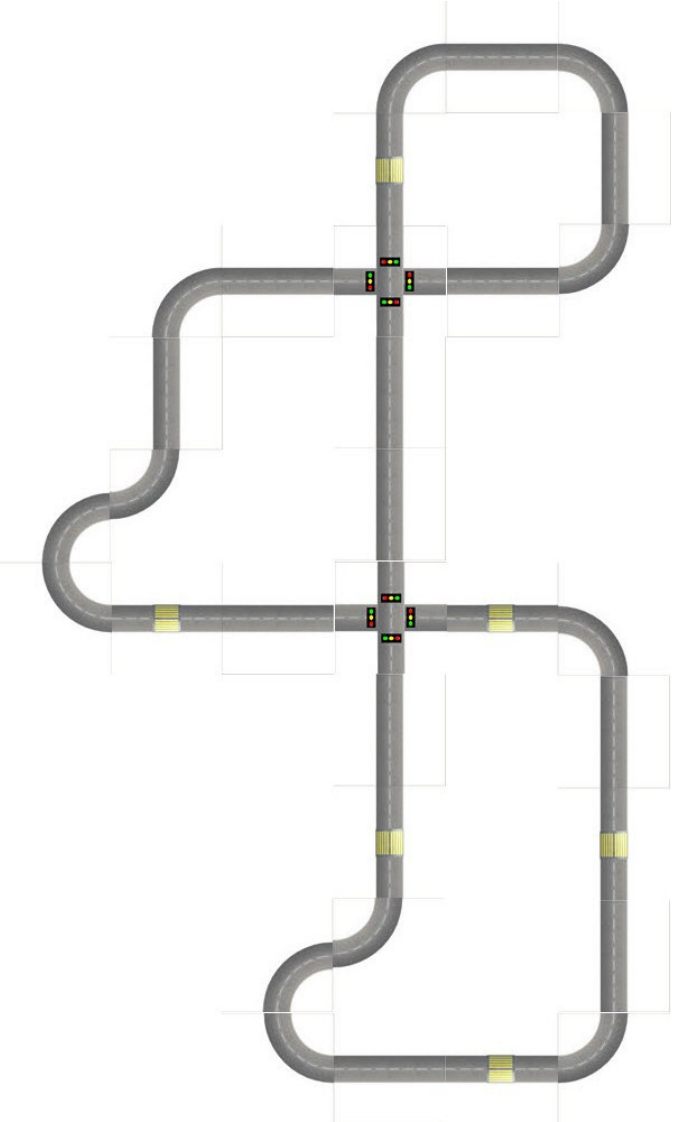

Fig. 2: A sample road track that can be generated by feeding the path generator using prefabs at difficulty levels that correspond to the dexterity abilities of a given patient. Such road tracks can better serve the individual rehabilitation needs of a given patient as dictated by the attending physiotherapist.

Each game scene is dynamically generated by a custom path generating agent which picks random components from the collection of pre-fabricated (appropriately called “prefabs”) components shown in Fig. 1, and places them one after another according to rules dictated by a behavior array. Each prefab is associated with a small integer number which represents the difficulty of the associated gesture that must be performed by the patient so that it is detected in the game and makes a racing car perform the required action: continue straight in (a), decelerate and stop at the zebra crossing in (b), turn left (c) or right (d) or stop at a traffic light (e). The level of difficulty associated with each prefab can be customized according to the level of mobility of the patient and how difficult it is for him/her to e.g., perform the gesture to turn left vs the gesture to turn right. The path generated can be a closed path, as shown in Fig. 2 or an open path.

III. Summary

In this work we present elements of a racing game that is tailored to Parkinson’s disease which allow for customization on a per-patient basis. Accordingly, the game logic dynamically generates a racing track every time a patient works out based on the necessities determined by the physiotherapist and encoded in the difficulty levels of physically performing moves that correspond to gestures such as go / stop / turn. Modularity at design level makes it possible to introduce and implement the concept of progressive difficulty by e.g., increasing the frequency of more demanding tasks that are challenging for the specific patient or introducing more physically and / or cognitively demanding tasks.

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