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# A novel wearable laser device to regulate stride length in Parkinson's disease

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*Abstract*—**Decreased stride length is a highly relevant characteristic of the gait in patients with Parkinson's disease (PD). In this paper, a novel wearable laser device for stride length regulation is presented. The device is mounted to one foot and can project a red laser light strip to the floor as a visual cue for the other foot. In the experiment twelve healthy volunteers walked a 20 m straight walkway wearing the system on both feet. As an objective result, the stride length regulation reached an accuracy of 96.1±2.5 (94.0±3.5) % for a pre-defined stride length $\lambda_{def}$= 55 (65) cm. The subjective evaluation by the participants using a questionnaire revealed that the visual cue projected from the laser device was considered a stable signal that did not shake during walking. 6 of 12 participants felt that this device was not interfering with their gait, 3 of 12 judged this aspect neutrally, and 3 of 12 considered it somehow bothersome.**

## I. Introduction

Parkinson's disease (PD) is a highly prevalent neurodegenerative disorder that leads to basal ganglia dysfunction typically resulting in bradykinesia (slowness of movement), rigidity (muscle stiffness) and tremor (rhythmic oscillating movements of the limbs or the head). Besides these cardinal symptoms the parkinsonian gait disorder with motor blocks is a hallmark of PD, and affects up to 80% of patients during the course of the disease [1].

The decreased stride length of parkinsonian gait (hypokinesia) is associated with freezing of gait (FOG) and festinating gait [2] [3] [4]. FOG was defined as a sudden and transient inability to carry out effective stepping [5]. Patients describe FOG as a feeling as if their feet were stuck or frozen to the ground. Festination is an involuntary shortening and hastening of stepping to keep the body in the center of gravity [6]. During festination and before episodes with FOG the stride length decreases while the number of steps increases [7]. This decrease of stride length is regarded as a characteristic feature of festination and FOG. According to Chee et al, this mechanism contributes essentially to the pathophysiology of FOG in PD patients [8].

More than half of the patients with a disease duration of over five years have experienced FOG [9]. Sudden occurring episodes of FOG and festination lead to disturbances of balance that increase the risk to fall [10]. The daily activities of PD patients with FOG are restricted, and their quality of life is impaired.

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## II. State of the Art

Besides pharmacotherapy and electro stimulation of the brain, physiotherapy, which comes in a multitude of various forms and shapes, plays an important role for the treatment of patients with PD. Ideally, the patient exercises diminished functions to increase activity and re-gain social participation. Physiotherapy that helps patients to use external sensory cues is one of the best evaluated methods for patients with PD [11] [12]. The effectiveness of visual cues to improve the gait of PD patients is firmly established, a normal stride length can thus be regained [13]. Evidence for a modest efficacy of external cueing devices using laser-light in reducing FOG conditions and falls was recently reported [10]. In reference [13] a visual cue stick as a treatment for FOG is introduced and evaluated. In study of reference [14] prototype of virtual cueing spectacles (VCS) is used to improve the gait of PD patients in the home and community. VCS is eyeglasses with electronic parts that provide user orange lights as visual cues. Visual floor markers like strips on the floor are often used by neurologists as an exercise intervention to regulate PD patients' gait parameter, for example, stride length [11] [13] [17]. Lewis et al. developed a subject-mounted light device (SMLD) for stride length regulation, which can be attached to the subject's chest and project two laser lines onto the floor in front of the subject [11]. Recently scientists also used treadmill training with virtual reality that displays visual cues in different environments for gait research and rehabilitation of PD patients [18].

In table I a summary of the state of the art is shown.

TABLE I. Summery Of The State Of The Art

| Ref. | Device | Location | Mobility | Steadiness | Symmetry |
|---|---|---|---|---|---|
| [13][15] | Stick with visual cues | In hand | + | + | - |
| [14] | VCS | Head | + | + | + |
| [13][17] | Visual floor markers | On floor | - | + | + |
| [11] | SMLD | On chest | + | - | + |
| [18] | VR Treadmill System | In room | - | + | + |

VCS stands for virtual cueing spectacles, SMLD stands for the subject-mounted light device, VR stands for virtual reality, symbol "-" stands for negative and "+" for positive. "Steadiness" describes the stability of visual cues and "symmetry" describes the pattern of gait.

Among these previous studies there are effective approaches that can help PD patients improve their gait. But the use of some instruments like VR Treadmill System is limited in time and scope. The setup of these instruments is for patients also too complex. Stick with visual cues can contribute to the mobility of patients. However, the symmetry of natural gait will be disturbed concurrently. Because of the body swing during walking, the visual cues produced by subject-mounted light device may be not stable.

## III. Task And Approach

The goal of the presented project is to develop a wearable laser device that can be used not only for reducing the freezing-episodes but also as an effective instrument for gait-rehabilitation in PD patients. This wearable system should offer stable laser light strips as visual cues on the floor in front of the subject. Moreover, the laser device should be unobtrusive for patients and be usable in everyday life.

## IV. Static System concept description

The wearable laser device consists of two main parts: laser-electronic module (A) and support structure (B). The laser module (2) is able to project a red laser light strip (6) on the floor in front of the subject. Slope of the light strip and distance between the light strip and laser device can be adjusted by turning the laser module as the double-headedarrows in Fig 1. A. showed. The electronics unit (1) includes electronic circuit and battery. If the battery needs to be charged, only the laser-electronic module is required. Therefore, Part A and B should be able to be separated from each other. As the dotted arrows demonstrated in Fig 1, forces exerted by shoe and Velcro tape are applied to the base plate (4) of the support structure. A thin sensing device (5) like membrane button pad or membrane pressure sensor should be integrated into the base plate in order to examine the position of the foot: on the floor or in the air.The wearable laser device can be mounted to shoes using a Velcro tape (3).

## V. Dynamic System concept description

In order to use the light strips projected from a laser device, which is mounted to the subject, as visual cues like the stationary floor markers, sufficient stability of the light strips on the floor must be achieved. This is always an unignorable obstacle in correspondingresearches. The reason is that it is extremely difficult to find a constant static position of the body in walking. A tiny shakiness of the laser device either on the belly [11] or on shoes [19] may lead to greatly amplified swaying of the light strip on the ground. In order to solve this puzzle, a hard look should be taken at the human gait cycle. It is expected that at least a temporarily stable position in the human body can be discovered in walking.

According to [20] there is only one foot at a time that has contact with the ground when running. In contrast, a period of double-support will appear during walking. A gait cycle can be divided into two phases: swing phase and support phase. Positions of left leg during its support phase and right leg during its swing phase are shown in Fig 2. The swing phase of right foot (white), when the leg is swinging forward in the air, lasts from the state “right toe off” to the state “right initial contact”. The support phase of the left foot (gray) is the time interval, when the left foot is on the ground.

We can see that if one leg, for example the right leg, is in the swing phase, as shown in Fig 2, the left leg must be in the support phase in themeantime. In this time interval the left foot supports the weight of the whole body. Namely, it must hold up a greatly heavy burden. If the left foot is wavering in its support phase, the subject will be unable to continue his walking and may even fall. Therefore, in that moment the contact point between the left foot and the groundmust be temporarily static and highly stable. Based on this principle, the base plate of the aforementioned laser device can be fixed to this momentarily stable position. When the sensing device in the base plate detects this support phase of one foot, the laser module, which is fastened firmly to the base plate, will project a stable light strip on the floor. For example, as shown in Fig. 2 a) - c) below, the laser device on the left foot supplies a stable red light strip on the floor as a visual cue for the right foot, which is in its swing phase. When the support phase of right foot starts, as shown in Fig. 2 d), the second red light strip will be projected from the right foot onto the floor as a goal for the left foot to achieve. In this way, the subject is oriented towards the alternately presented light strip on the floor during walking and the stride length can be regulated. Moreover, When FOG episodes appear, a Parkinson patient with this laser device can utilize the laser light strips on the floor as visual cues to overcome FOG and continue his gait [21].

## VI. Evaluation

For evaluation, the concept introduced above was implemented as described in the following section VI.A and an objective experiment was designed and performed. The purpose of the experiment, described in section VI.B, is to

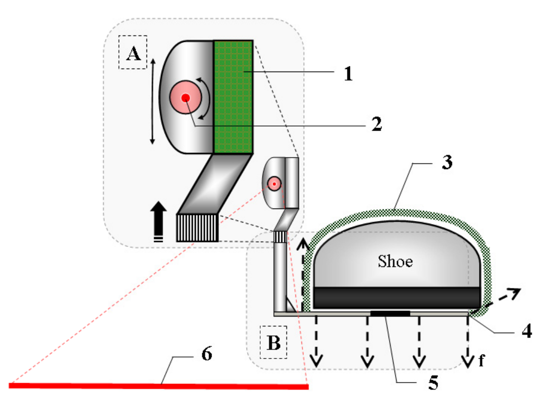


Figure 1. Description of the system’s parts of the wearable laser device. Electronics unit (1), laser module (2), velcro tape (3), base plate (4), sensing device (5) and laser light strip (6).

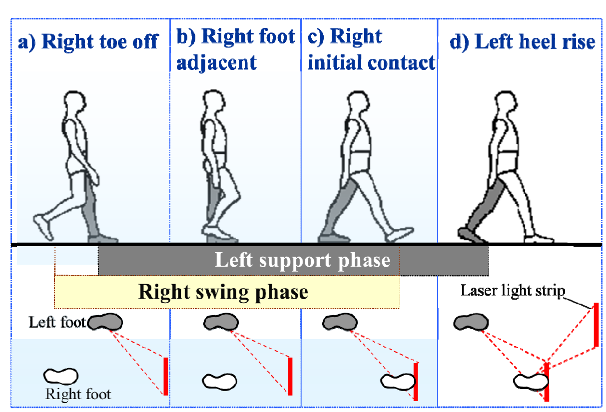


Figure 2. Positions of the left leg (gray) during its support phase and the right leg (white) during its support phase.

evaluate the accuracy of the stride length regulation. In addition, a subjective evaluation was carried out to investigate other important characteristics of the laser device.

### *A. Material and Methods*

A prototype of the wearable laser device is shown in Fig. 3. It consists of a support structure (1) and a laser-electronic module (2), which can be separated from each other. The laser-electronic module is composed of a 5mW laser module, an electronics unit and a rechargeable battery unit. The laser module (3) can be rotated to adjust the distance between the foot and the laser light strip. A small switch (4)is located on the top of laser-electronic module. A membrane button pad FT 01K SCHW is integrated in the center of the base plate (5) of the support structure, which can be mounted onto the shoe in the area of forefoot using a Velcro tape (FASTECH, AG) (6).

The rechargeable battery unit provides a voltage of 3.3 volt to the electronics. This battery unit includes the following elements: an accumulator with a capacity of 350 mAh, a charging chip MAX1555 (Maxim Integrated Products, Inc), a voltage regulator XC6204 (TOREX Semiconductor, Ltd), a green LED for reporting status of charging and a mini USB socket to connect to PC using a mini USB cable.

The mechanical parts of this laser device are printed by a standard 3D printer using Polyamide PA2200 plastic material. The base plate under the shoe is $100 \times 40 \times 2$ mm$^3$ in size. The entire device weighs 45 g and its height is 8.5 cm.

### *B. Experiment*

#### *1) Motivation*

By experiment the accuracy of the stride length regulation is evaluated. Moreover, a subjective evaluation is implemented in order to explore other important characteristics of this device, such as the light strip's stability.

#### *2) Set up*

12 healthy volunteers (age between 22 and 89, median age 27; leg length:92.7$\pm$7.6cm) put on the laser devices to both shoes, adjusted the distance between light strip and toe to a defined length $\lambda_{def}$ and walked five to ten minutes as anexercise  to adapt themselves to the new instrument. Then the participants were asked to walk straight along a 20 m walkway, which was marked using two strips at the initial position and the end position on the floor, respectively. The walking trail was recorded simultaneously using a digital video camera.

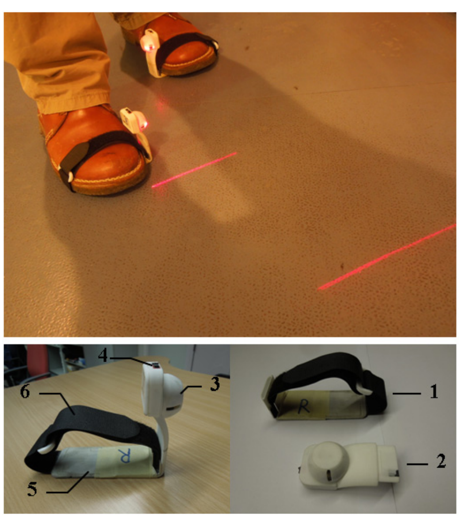


Figure 3. Above: wearable laser device in use for regulation of stride length. Below, left side: prototype of laser device.Below, right side: two separated parts of a laser device: support structure (1) and laser-electronic module (2).

Each participant should firstly place both toes next to the strip at the initial position and then start his/her walking. At the end of the walkway, participants were not required to reach the second strip exactly. The distance Δd between the toe position of last stride and the end position of the walkway was measured. In addition, the distance between each toe and corresponding light strip was also measured at the end in order to investigate the deviation of defined stride length after walking.

The accuracy of the stride length regulation using the wearable laser device is calculated as follows (equ. 1-2):

$$\lambda = \frac{L - \Delta d}{n} \tag{1}$$

$$Accuracy = \frac{|\lambda - \lambda_{def}|}{\lambda_{def}} \times 100\% \tag{2}$$

Where λ refers the actual stride length, L=20 m is the length of defined walkway, n refers to the number of steps. Δd refers to the distance between the toe position of last stride and the strip at the end of the walkway. In study of reference [13], the 95% confidence interval of stride length in control subjects was between 61 cm and 69 cm, in PD patients at baseline was between 48 cm and 49 cm and in patients with visual cues and retention conditions was between 66 cm and 67 cm. Therefore, in this study the defined stride length $\lambda_{def}$ was set to 55 cm and 65cm for two experiments for every subject.

After the experiments, the participants were asked to fill out a questionnaire for subjective evaluation of the developed prototype. The *visual analogue scale* (VAS) was used in the assessment. According to their level of agreement to the VAS items participants indicated a position along a continuous line between two end-points, as depicted in Fig 4. Important characteristics of the device and first user impressions were investigated in the survey.

#### *3) Results*

Table II summarizes the means and standard deviations of actual stride length, accuracy of stride length regulation and the set stride length after experiments. The calculated actual stride length for $\lambda_{def}$=55 cm was 54.3$\pm$2.5 cm with a maximum error of 4.4 cm and for $\lambda_{def}$=65 cm was 61.3$\pm$2.6

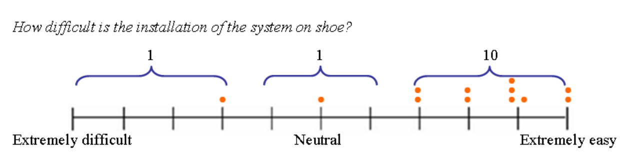


Figure 4. Visual Analog Scale (VAS) about the degree of difficulty of the system's installation.

cm with a maximum error of 7.0 cm. The prototype of the wearable laser device reached high accuracies of stride length regulation of 96.1 ±2.5 % for $\lambda_{def}$=55 cm and of 94.0 ±3.5 % for $\lambda_{def}$=65 cm. Because of the legs' movements during walking the position of the devices on the shoes may be no longer consistent with the set position. After the experiments the set stride lengths of the left foot changed to 54.7±1.3 cm for $\lambda_{def}$=55 cm and to 64.8±1.7 cm for $\lambda_{def}$=65 cm, which was similar at the right side. The small changes of set stride length after walking demonstrate the steadiness of the wearable device's position on the shoe.

TABLE II. OBJECTIVES RESULTS OF STRIDE LENGTH REGULATION

| Defined stride length $\lambda_{def}$ | Actual stride length $\lambda$ | Accuracy of stride length regulation | Set stride length after exp. (left foot) |
|---|---|---|---|
| 55 (cm) | 54.3±2.5 (cm) | 96.1 ±2.5 (%) | 54.7±1.3 (cm) |
| 65 (cm) | 61.3±2.6 (cm) | 94.0 ±3.5 (%) | 64.8±1.7 (cm) |

With the aid of the questionnaire we get the opportunity to explore important subjective characteristics or attitudes of the developed prototype, which cannot be directly measured. Unequivocal participants' responses denote that installation of the system on the shoe was effortless, as shown in Fig 4. The responses about the interference on their locomotion with the wearable device were heterogeneous. Six out of the participants thought the device was unobtrusive. In contrast, three participants' opinions were negative and three participants' statements were neutral. According to the responses it was undeniable that the light strip on the floor was not shaky during walking. Five participants thought the light strip was stable and the other seven had a neutral opinion.

## VII. CONCLUSION

The first prototype of a wearable laser device for stride length regulation was presented. The accuracy of the regulation was evaluated, and the result was satisfactory as the expectation of 90% accuracy was exceeded. Based on the results of the subjective evaluation, the laser light strips were stable and considered as suited as a visual cue. The device should be utilized for stride length regulation in further experimental work. In a next step a microcontroller with a membrane pressure sensor instead of the button pad will be integrated into the system to further improve the stability of the light strips on the floor. The accuracy of stride length regulation then needs to be evaluated in patients with PD and FOG in order to determine its therapeutic usefulness, e.g. a reduction of FOG episodes.

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