ORIGINAL RESEARCH
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Characterization of walking gait features using Kinect

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ABSTRACT

The examination of the human gait cycle can be useful for physiotherapists for identifying and/or predicting body motion disorders and it provides important data about the patient's condition in many ways. In this paper, the progress of a special TheraSuit physiotherapy treatment of a child, who has reduced mobility due to cerebral palsy, has been investigated. Generally, this type of disorder is classified into strict levels and the effectiveness of the therapy is expressed by changing between distinct levels. On the other hand paper describes a new markerless self-developed movement analysis system, which is able to show the effectiveness of the treatment with quantitative parameters. These parameters are determined by statistical methods.

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1. INTRODUCTION

Human gait analysis provides information about the patient's health condition. Typically the gait cycle of a patient is evaluated by sight; however, in most cases, experts need a lot of information, which is generally not available, for choosing the best treatment for the patients. In general, it is important to predict and observe different musculoskeletal disorders, like Parkinson-diseases, Cerebral Palsy in time, for prevention [1, 2]. This type of disease affects the pattern of movements and causes an uncertain and trembling gait.

Nowadays, the physiotherapist are able to determine the markers of disorders only by visually, but it is based on only subjective opinion and knowledge. The advanced gait analysis needs to involve various solutions and tools.

For recording the gait cycle, different methods can be used, for example wearable sensors [3, 4]. Large number of researchers working with deployed systems like VICON Plug-in Gait [5, 6], where up to eight cameras are used for the measurement.

In this research, the progress of special TheraSuit treatment of children with different ages and with reduced mobility is examined. The TheraSuit therapy is based on a special suit, and belongs to a modern and advanced kind of therapy. This type of medical aids [7] can increase the daily well-being and success of recovery. The progression and the efficiency measurements based on international standards [8, 9] and they are typically based on predefined affect levels [10, 11].

The developed measurement environment is a visual-only system that uses a Microsoft Kinect v2 sensor and MATLAB scripts that capture and process the data. Before the evaluation process, the data is filtered and the noise is reduced and finally the analyzer script helps to identify the gait cycle phases. A graphical display shows the most important parameters for the calculations.

Based on the international standards and literature [12], which describes the necessary parameters and limitations for gait cycle phases identification. The presented measurement

method provides the spatial and angular curves of different joint and information for the gait cycle phases as Heel Strike (HS) and Toe Off (TO). Based on the gait cycle phases, the effect of the intensive TheraSuit therapy progression was examined. Current research is to investigate the effects of TheraSuit intensive therapy on gait pattern of children with cerebral palsy (cadence, walking velocity, step length, etc.).

In this paper, statistical methods [13] have been used to show significant changes before and after the therapy.

2. MEASUREMENT AND SOFTWARE BACKGROUND

2.1. The measurement environment

The measurement for the analysis of the human gait in wireless and markerless environment is not a simple task. The measurement system is relies on the widely used Microsoft Kinect v2 sensor and a PC-based data processing environment [14, 15].

The sensor system consists of two different types of cameras; the first is an Red-Green-Blue (RGB) camera while the other is an infrared aided depth-camera. The sensor can identify up to 6 persons, and it can show the identified skeleton models of the persons as well. The skeleton model contains 25 connection points or joints for each body in a 3-dimensional space, and the corresponding points are presented by x, y, z coordinate values. The directions are the following: the z axis is in the sagittal plane and it represents the absolute distance between the patient and the sensor, the y axis is perpendicular to the ground surface (transverse plane) and points from the ground to the sensor, and finally the x axis is in the coronal plane and perpendicular both to z and y axis.

Figure 1 shows the measurement environment, a) the sensor was fixed on b) a tripod to stabilize the camera, and c) a notebook for data recording and processing with the frame rate 25–30 frame per second (fps).

Fig. 1. The measurement environment: a) Kinect v2 sensor; b) camera tripod; c) PC for communication and data processing

2.2. Software environment background

For the measurement and data evaluation MathWorks MATLAB was used, which can be used for different image processing tasks [16].

During the measurement, the graphical display of the system shows the cycle or iteration counter, which can be used for timing and calculating the frame rate. The bodies on the graphical display (as it is shown in Fig. 2) can be distinguished by colors, because, a custom color-map for different body indexes have been created.

During the measurement, the patient walks toward the sensor (Fig. 3), and the application records the gait cycles, in a complex MATLAB object, which includes the coordinates of all joints, for all recorded bodies and the timestamps as well.

The recorded data and a handwritten report about measurement conditions (name, therapy, the form of exercise, etc.) are transferred to the processing computer. To be sure that the measurement object is successfully created, the self-developed preview application can be used to check it
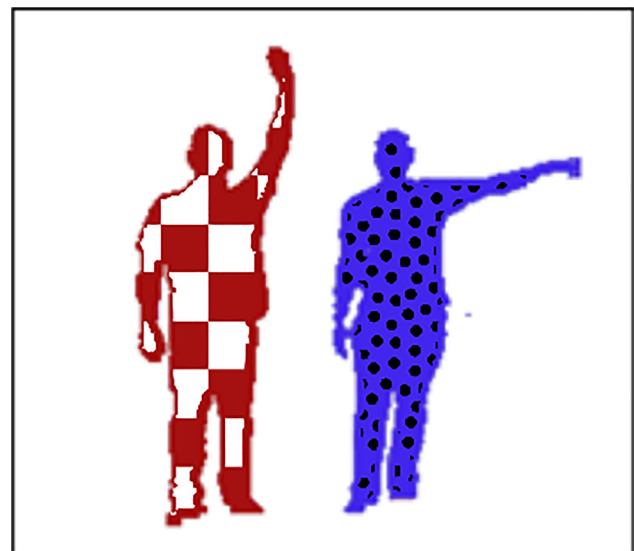

Fig. 2. Tracking multiple people using Kinect; using the color information the patient and therapist can be marked and selected for post-processing
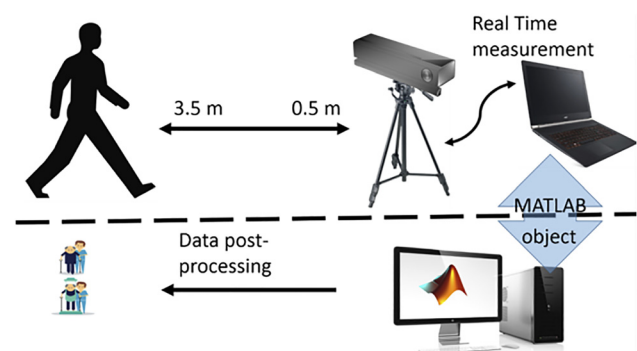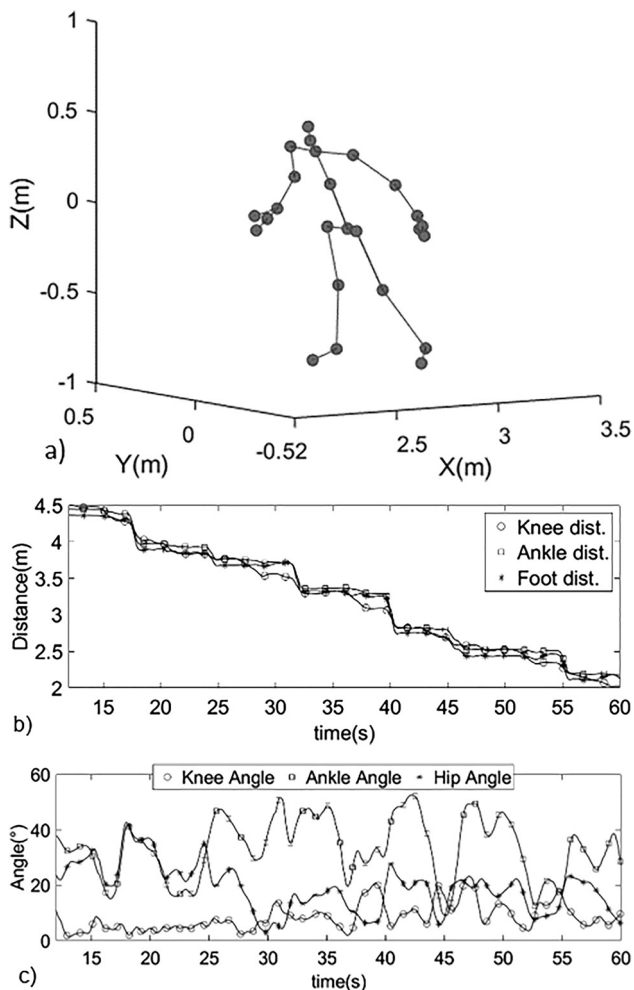

Fig. 3. The measurement setup

Fig. 4. a) The skeleton model for gait cycle record; b) distance records; c) angular data
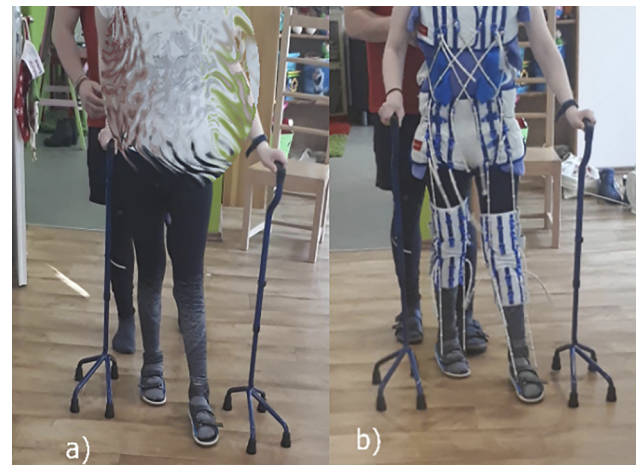

Fig. 5. a) The patient before the therapy without the TheraSuit; b) wearing the special suit during the rehabilitation process

In Fig. 5 all cases can be seen before-after, with or without the special suit.

3.2. Statistical investigation of the treatment efficiency

In order to prove the effectiveness of the TheraSuit treatment two types of statistical methods have been used. During the gait monitoring two parameters have been calculated from the measurements, the length of the steps and the time of the gait.

During the evaluation the limitation of Kinect v2 sensor has to be considered because only 5–7 steps could be recorded, and because these children can take less physical stress. In this paper only the gait cycle with and without the TheraSuit have been examined and presented, which is only a part of the whole measured movement variations (gait cycle, stabilization, stand up and sit down actions, etc.). Their gait could be recorded only twice. The aim was to investigate whether there is any significant change in the step length and in the velocity of the gait as result of the TheraSuit treatment.

The investigated hypotheses were:

– in the first case two-tailed student's test has been applied and the null hypothesis was that the treatment has no effect, and there is no significant change in mean of the step lengths and in the velocity of the gait;
– in the second case a one-tailed Mann-Whitney U-test has been used, and the same null hypothesis was tested against the alternative hypothesis which was that the mean of the step lengths increases and the velocity of the gait is smaller;
– the significance level was 5% in each case.

Fluctuations both in step length and velocity are natural in a gait. If these fluctuations follow the normal distribution, then the inference about two means based on the student's t distribution (the so-called two-sample t-test) can be applied.

visually. As a result the recorded data can be seen together as visualization, shown in Fig. 4.

It shows the recorded model and the selected joints together. Using the preview the measurement and the body ID can be verified. The preview application is based on the earlier development [17].

3. MEASUREMENT SCENARIO

3.1. Statistical investigation of the treatment efficiency

This paper describes a measurement model and discusses the significant improvements of the therapy process with the special TheraSuit treatment, where the examined child who has a movement disability, reach significantly better motion capability. Our research group took several occasions to measure and records the child's gait, to compare the results and show the possible improvement. During recording the child moving toward the sensor the child normally uses a crutch for walking, so it has been recorded and measured with this medical aid.
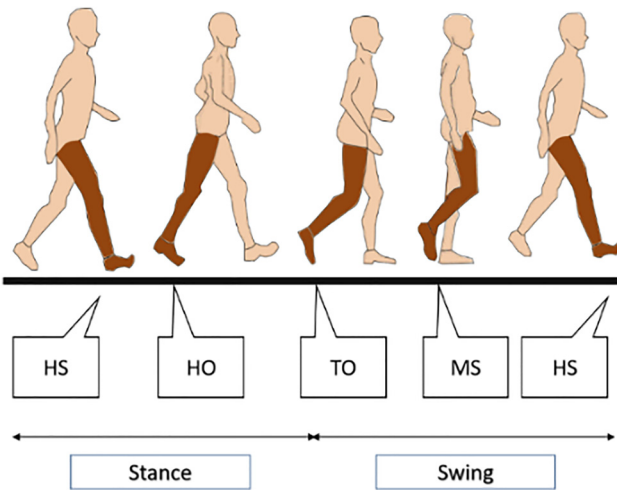
Fig. 6. Gait cycle phases

4. DATA PROCESSING

4.1. Gait cycle analysis

Figure 6 shows that the human movement can be divided into two different states, and four phases [18]. The stance phase is, where on the examined side the feet is in contact with the ground, and the swing phase is, when the leg swings forward. The stance phase can be split into three separate sub-phases, Heel Strike (HS), Heel Off (HO), Toe Off (TO). The Middle Swing (MS) belongs to the swing phase.

In this case the examined patient is disabled in movement, so the phase definition is harder than usual. The recorded data lets identify the gait phases, however in this paper only two of them, HS and TO, will be considered, as two phases are enough for the calculations.

4.2. Measured and calculated parameters

The research focuses on the gait patterns, and the corresponding measured parameters are the lower limb coordinates.

For the gait phase identification, mainly the spatial ankle data in the sagittal plane (along the z axis) was used. The HS and TO gait cycle phases with its timestamps provided enough information for gait cycle parameters as cadence, which is the number of steps in unit time, velocity and step length.

For extracting the HS and the HO from the figure, a manual selection had to be applied. In this way the identification is more reliable. The distance and elapsed time between heel strike and heel off can be calculated from the measured points at each step. The extracted parameters can be used for calculations [19].

The cadence (1) in a minute can be extracted from the elapsed time between the first and last step as:

$$\text{cadence} = \frac{60}{\text{avg}(ds)} \cdot 2, \tag{1}$$

where the ds denotes the set of elapsed times between two consecutive HS event in seconds, which is equal to the

elapsed time of one step; and avg(ds) means the average elapsed time throughout the measurement.

The step length can be calculated from the average of the distances between HS points.

The velocity (2) is calculated from the quotient of examined distance and examination time as:

$$v = \frac{\text{Last examination point} - \text{First examination point}}{\text{Examination end time} - \text{Examination start time}}. \tag{2}$$

4.3. Data evaluation phase

The measurement processing contains three phases. The first phase is the selection, where the measurement supervisor can select the corresponding body ID from the complex object.

The selected body ID can be loaded in the preprocessing part, where the application takes care of de-noising and merging timestamps and coordinates.

The second action extracts the data and the desired variables and they are drawn in figures, where the y axis shows the measured quantities, the x axis represents the measurement in time.

In Fig. 7 the measured coordinates for the right and left ankle can be seen. The y-axis represents the absolute distance from the sensor in meter unit. The circle shows left ankle, and the cross-shape represents the right ankle.

5. RESULTS

5.1. Gait analysis results

As the ankle parameters are the most important values according to the post processing, its spatial distance from the Kinect sensor (as origin) is important for each heel strikes. The elapsed time and its differences are calculated parameters as well. The distance between two consecutive steps is calculated for the step length parameter. Table 1 shows the calculated parameters for the left lower limb and Table 2 shows the parameters for the right lower limb about one gait cycle measurement.
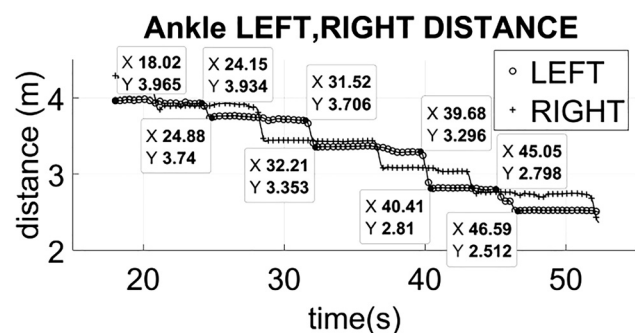

Fig. 7. Measured data for the left and right ankle, where the annotation shows the manually selected coordinates for HS and TO for the left ankle

Table 1. Timestamps and distances for the left lower limb heel strike

Time (s)	Distance (m)	dt (s)	ddist (m)
18.1	3.96		
24.8	3.74	6.7	0.23
32.4	3.35	7.6	0.38
40.6	2.81	8.2	0.54
46.5	2.51	6.0	0.30
55.6	2.20	9.0	0.31

Table 2. Timestamps and distances for the right lower limb heel strike

Time (s)	Distance (m)	dt (s)	ddist (m)
21.3	3.9	–	–
28.8	3.4	7.5	0.4
37.2	3.1	8.4	0.4
43.6	2.7	6.4	0.3
52.5	2.4	8.9	0.4
58.9	2.1	6.5	0.3

After the spatial and angular measured data are exported, the comparable values (cadence, step length, velocity) can be calculated before and after the treatment process with and without TheraSuit medical equipment. Table 3 shows the calculated parameters before and after the treatment with and without the TheraSuit medical equipment.

Applying the discussed statistical tests the extracted parameters have been tested by student's *t*-test with the specified null-hypotheses and significance level. The results show that there is no significant change in the step length but there is significant change in the velocity of gait. It means that the treatment has no effect to the step length but treatment process is resulted in significant improvement in the gait speed.

If the measured gait cycle parameters do not follow the normal distribution the nonparametric test, the Mann-Whitney U test can be used to investigate the efficiency of the treatment, with the same null-hypotheses and significance level. The results of the Mann-Whitney U test were the same: the treatment has no effect on the step length but has effect on the velocity of the gait.

Table 3. The examined gait parameters

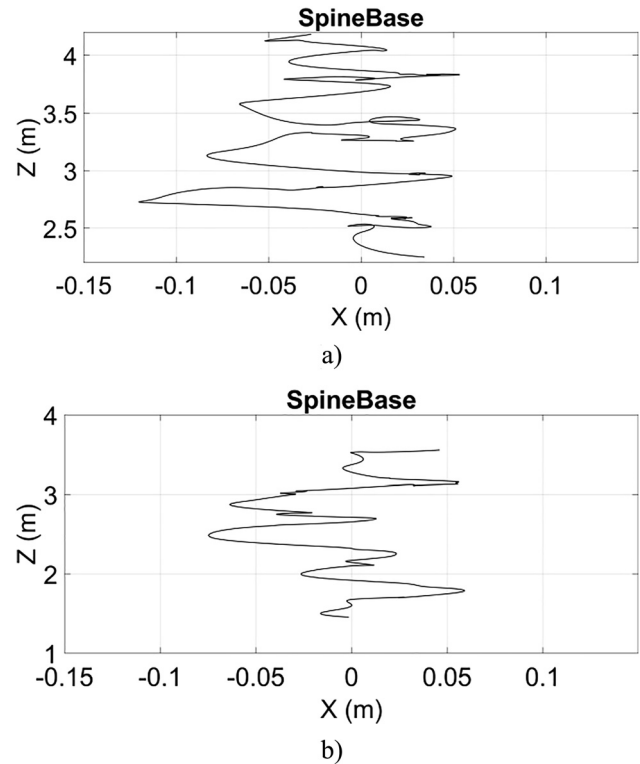|	Before the treatment		After the treatment	
	Without TheraSuit	With TheraSuit	Without TheraSuit	With TheraSuit
Number of steps (1/min)	16.00	18.90	26.30	33.40
Step length (m)	0.35	0.35	0.33	0.36
Velocity (m/s)	0.05	0.06	0.07	0.10

Fig. 8. a) The spine base without and b) with TheraSuit

5.2. Stability results

The gait before the treatment was uncertain and the spine base was swinging during the movement. Figure 8 shows the spine base without and with the special suit.

The figure shows, that while the special suit was worn, the spine base is more stable, and the number of curves and uncertain swinging movements disappear. Beside of this the child's gait was more precise and swinging less, after the treatment.

6. SUMMARY

In the paper a method for the efficient and reliable measurement of every relevant geometrical parameter of the human gait with the application of Microsoft Kinect v2 sensor, and an environment for the effective processing and analysis of the measurement data have been proposed. The constructed measurement setup is suitable for measuring in different conditions and environments.

It was also demonstrated that the developed system can be used for monitoring the rehabilitation process during a medical therapy affecting the gait cycle. It this case the goal was to validate the significant progression in the pace of walk as the result of the therapy using statistical methods.

It was also shown that the measurement data is applicable for the proper characterization of various aspects of the human gait by extracting relevant information, and the developed system can be used to analyze gait cycles based on

spatial joint coordinates. The system is capable to monitoring the human gait in real-time even under disturbing environmental conditions as medical aids and supporting therapist during the measurement.

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