Czech Technical University in Prague

F7

Faculty of Biomedical Engineering
Department of Biomedical Technology

Correlation between weight distribution and center of pressure with spinal alignment using Nintendo Wii Balance Boards and Kinect V2 camera

Bachelor Thesis

Noa Bar

Supervisor: Ing. Petr Volf
Field of study: Biomedical Technician
Subfield: Biomedical and clinical technology
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BACHELOR'S THESIS ASSIGNMENT

I. PERSONAL AND STUDY DETAILS

Student's name:	**Bar Noa**	Personal ID number:	**453867**
Faculty:	**Faculty of Biomedical Engineering**		
Department:	**Department of Biomedical Technology**		
Study program:	**Biomedical and Clinical Technology**		
Branch of study:	**Biomedical Technician**		

II. BACHELOR'S THESIS DETAILS

Bachelor's thesis title in English:

Correlation between weight distribution and center of pressure with spinal alignment using Nintendo Wii Balance Boards and Kinect V2 camera

Bachelor's thesis title in Czech:

Korelace mezi distribucí hmotnosti a centra tlaku s tvarem páteře za využití stabilometrických plošin Nintendo Wii a kamery Kinect V2

Guidelines:

The goal of this thesis is to create software solution in Matlab which will enable to check for correlation between the weight distribution across an individual's feet and center of pressure to spinal alignment. In order to get the required data the software solution will use two Nintendo Wii Balance boards and one Kinect V2 camera. The use of IR camera, together with reflective markers will provide a reliable way to measure the subject's spinal position. Test your proposed software solution at least on a set of 15 probands holding four different postures (standing with close feet, with feet wide apart, with the right foot in front of the left and with the left foot in front of the right) and evaluate statistically.

Bibliography / sources:

[1] Gonzalez, R.C., Woods, R.E., Eddins, S.L., Digital Image Processing Using MATLAB, ed. 2, Pearson Education, 2004, 620 s., ISBN 8177588982

[2] Menache, A. , Understanding Motion Capture for Computer Animation, ed. 2nd Edition, Morgan Kaufmann, 2011, 276 s., ISBN 9780123814968

[3] Ingle, V., Proakis, J., Digital Signal Processing Using MATLAB, ed. 3, Cengage Learning, 2011, 624 s., ISBN 9781111427375

Name of bachelor's thesis supervisor:

Ing. Petr Volf

Name of bachelor's thesis consultant:

doc. Ing. Jiří Hozman, Ph.D.

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Assignment valid until: **20.09.2020**

prof. Ing. Peter Kneppo, DrSc.
Head of department's signature

prof. MUDr. Ivan Dylevský, DrSc.
Dean's signature

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Declaration

I hereby declare that I have completed this thesis with the topic " Correlation between weight distribution and center of pressure with spinal alignment using Nintendo Wii Balance Boards and Kinect V2 camera " independently and I have included a full list of used references. I do not have a compelling reason against the use of the thesis within the meaning of Section 60 of the Act No 121/2000 Coll., on copyright, rights related to copyright and amending some laws (Copyright Act).

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Abstract

As posture and balance disorders can be a sign of other medical conditions and affect the daily routine of people, it is important to watch for signs their deterioration. Monitoring these parameters is also important in mild cases of spine-related medical conditions, such as Lordosis, Kyphosis and Scoliosis, which can worsen over time.
This thesis attempts to check if a correlation exists between spinal alignment, center of pressure (COP), center of gravity (COG), and weight distribution between the feet in adults. A Matlab algorithm was created to collect data from both a Microsoft Kinect V2 and two Nintendo Wii platforms(WBB), analyze it, and calculate the COP, COG, weight distribution, and spinal alignment.
The experiment consisted of placing reflective markers on six anatomical points along the spine, and measure fifteen subjects in four different standing positions while they stand on two Nintendo WB Boards; with close feet, open feet, the left foot out front, and the other way around while the Kinect recognize the markers positions.
The data is then collected and analyzed by an algorithm which was built to translate the subjects data.
The Data was recorded and analyzed in Matlab.

Keywords: Balance,spine position, Nintendo Wii Balance Board, Posture, Weight, Center of Pressure, Microsoft Kinect v2

Supervisor: Ing. Petr Volf

Abstrakt

Vzhledem k tomu, že poruchy držení těla a problémy s rovnováhou mohou být znakem zdravotních problémů a ovlivňují každodenní život, je důležité sledovat jejich případné zhoršení. Monitorování těchto parametrů je důležité v případě problémů spojených s páteří, jako je lordóza, kyfóza a skolióza, které se mohou postupně vyvíjet.
Tato práce se snaží ověřit, zda existuje korelace mezi tvarem páteře, centrem tlaku (COP), těžištěm těla (COG) a rozložením hmotnosti mezi dolními končetinami u dospělých.
Experimentální měření sestávalo z aplikace šesti reflexivních markerů na anatomické pozice páteře a bylo ověřeno na 15 probandech v rámci čtveřice různých typů postoje na dvojici stabilometrických plošin Nintendo WB Board; chodidla u sebe, chodidla od sebe, levé chodidlo před pravým, pravé chodidlo před levým, přičemž MS Kinect byl využit k rozpoznávání markerů.

Data byla zaznamenána a analyzována v prostředí Matlab.

Klíčová slova: Rovnováha, Poloha páteře, Nintendo Wii Balance Board, Postura, Hmotnost, Centrum tlaku, Microsoft Kinect v2

Překlad názvu: Korelace mezi distribucí hmotnosti a centra tlaku s tvarem páteře za využití stabilometrických plošin Nintendo Wii a kamery Kinect V2

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List of abbreviations

Abbreviation	Meaning	Unit
COG	Center of Gravity	[-]
COP	Center of Pressure	[-]
CTU	Czech Technical University	[-]
FBME	Faculty of Biomedical Engineering	[-]
FP	Force Platform	[-]
IR	Infra Red	[-]
MKV2	Microsoft Kinect Version 2	[-]
OMC	Optical Motion Capture	[-]
TOF	Time of Flight	[-]
S.D	Standard Deviation	[-]
SW	Software	[-]
WBB	Wii Balance Board	[-]

Table 1: List of used abbreviations

Chapter 1

Introduction

Posture defines as "The position in which someone holds their body when standing, sitting or lying down"[32], and 'good posture' can be defined as "the correct alignment of body part supported by the right amount of muscle tension against gravity"[33].
The maintenance of stable posture and balance in humans is possible due to the Postural Control system, composed of three recognized subsystems.
Those subsystems are the Central nervous system (CNS), the Sensory system - which includes the visual and proprioceptive systems - and the musculoskeletal system[3]. The vertebral column, commonly known as the spine, is an important part of the latter; It consist of a sequence of 33 vertebrae, separated by inter-vertebral discs, allowing for head, neck and body movements, as well supporting an upright posture.
The human spine is naturally 'S' shaped, the curvy shape allow it to absorb shocks better, as well as giving support for the head, allowing optimal stabilization and help with maintaining a good posture. It also allow better flexibility during movements and bending. There are 3 main curves in the spine; the top one is the Cervical curve, which located along the neck and consist of 7 vertebrae (C1-C7). The second curve is the Thoracic curve, consist of 12 vertebrae and situated along the thorax (T1-T12) and the third region - the Lumbar curve - is made from 5 vertebrae and located along the lower back[8]. Those curves can be divided into two categories; 'Lordotic curves', which are concave - this category include both the Cervical curve in the neck and the Lumbar curve in the lower back. The second category is the 'Kyphotic curves' - which are convex and includes the Thoracic curve [15]
Another two regions of the spine are the Sacrum and the Coccys (commonly known as the tailbone), which consist of groups of vertebrae fused together. [8].

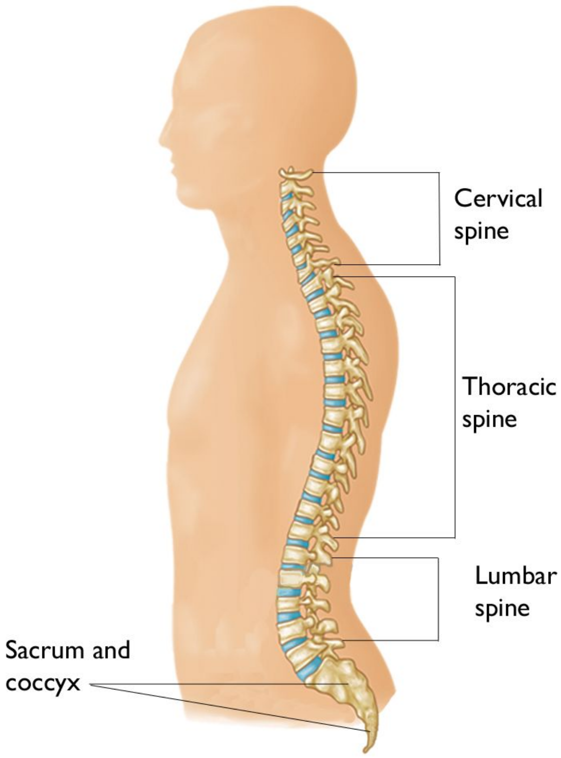

Figure 1.1: Different segments of the spine[25]

However, while curved spine is natural, sometimes one or more of the curves is too concave or convex, or that the spine is curved sideways, and those are medical situations which needs to be monitored and treated if needs; Some of the common spine deformations are Lordosis, Kyphosis and Scoliosis, which will be discussed more thoroughly in **1.1 steady state** section.

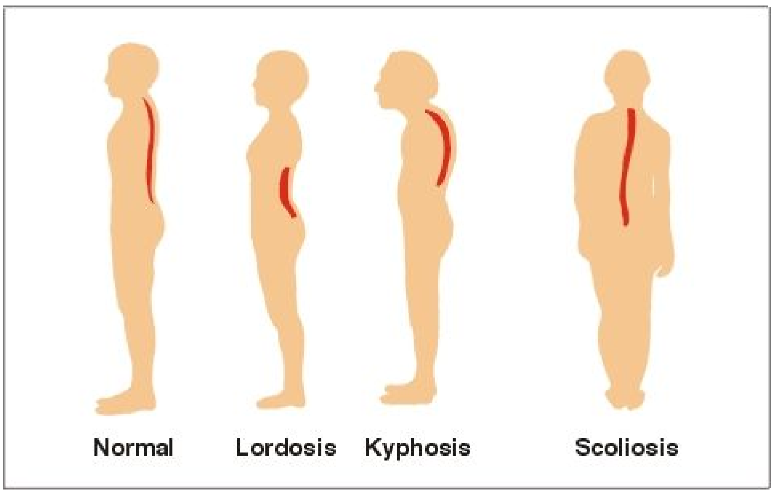

Figure 1.2: Illustration of various back problems[47]

Aside from the medical spine problems cases mention above, as well as various other medical spine and back problems, factors such as age[3], various injuries [10], or bad postural habits [7] can also affect a person's posture. Today's modern lifestyle, for example, encourages extended daily sitting in front of various screens, such as computer screens, smartphones or television, usually in unnatural positions. This awkward sitting exerts pressure on the spine and neck, in addition to shortening some muscles and lengthens others, which weakens the muscular support of the upper body.
Common symptoms of poor posture are neck and back pain as a result of pressure from sitting and bad head positioning, as well as headaches, poor balance and breathing problems. Ongoing research currently examines the effects of poor posture on mood, sleep and levels of fatigue[7], which have a great impact on quality of life.
For those reasons it is important to check one's posture on regular basis, regardless of existing medical conditions, and have an immediate feedback in order to catch a postural problem as soon as possible and apply treatment to stop it from worsening. Common treatment to improve poor posture is by different exercises and stretches which can improve the strength and flexibility of the core muscles – enabling better support for the spine[7].
Assessment of postural control is a factor commonly evaluated as part of wide range of clinical situations from gait analysis to assessing the risk of falls in old age [5] or to assess the efficiency of rehabilitation process after an injury[1].
Some of the common tools for postural assessment are the Berg balance scale, or the use of force platforms (FP) combined with 3D cameras to allow for a thorough analysis[5], but while those methods include visual assessment, they can miss important information; patients using maladaptive strategies to keep their balance, for example, putting pressure on other body parts in order to keep upright and avoid stressing the injured area [5]. Also, those tools and methods suffer from various drawbacks, such as high price, accuracy and sensitivity problems or heavy and not easy to transport and manipulate[4].
To get a better visual coverage, Optical motion capture systems (OMC), which are considered as the gold standard for determining joint angles, as well as angular velocity and moments at various body parts [2], are an accurate tool in postural assessment, but can get really pricey [6][9]
Existing researches [5][4] show that while not as precise as the FP, the Nintendo Wii Balance Boards (WBB) can be a good solution for measuring balance in non-specialized medical facilities[4], and when compared to an OMC system, Microsoft Kinect V2 (MKV2) achieved similar enough result to the OMC system and can be used as a useful, inexpensive tool for assessing postural control[5].
While using the Nintendo WBB and MKV2 could be a possible substitute that can be used for measuring balance and postural control in non-specialized medical facilities, as well as possible changes in the spine, there exists a need for a platform which will be a clear and easy way to connect the WBB and the Kinect to a computer, analyze the data, and provide effective and easily

understandable feedback, which is what the algorithm suggested in this thesis work is intended for.

1.1 Steady state

As mention in the introduction, spine and posture problems can affect daily life greatly; from troubles walking and performing other physical activities to pain and discomfort and can be a result of various causes such as injuries, bad posture or other medical problems related to the spine. Some of the common spine medical conditions are Lordosis, Kyphosis and Scoliosis;
Lordosis is the case of hyper curving in the Lordotic curves. It can affect the neck and lower back curves. Lordosis is usually a side-effect - or a result - of a different medical condition, such as dwarfism, genetic disorders, osteoporosis, bone cancer, various spinal malfunctions, and issues in the nervous-system, hip, or pelvis[15]. It can also result from poor posture or obesity. While not hereditary, it can manifest both at birth or later during life[16].
Lordosis may cause back pain, improper posture and unbalanced gait, as well as resulting in height loss. It is treatable by being more active, loosing weight if needed, paying attention to posture and proper standing, and by stretching and strengthening various muscles in the lower back, abdomen and hips areas[15]. Children and teens, which are still growing, might need special braces to help support the spine, and only in sever cases of Lordosis, a surgery is required[16].

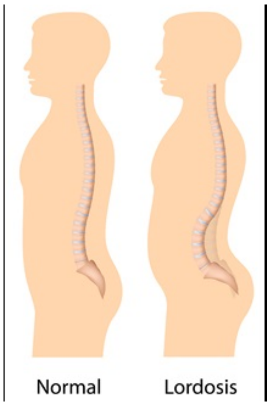

Figure 1.3: Lordosis Example[30]

Kyphosis is similar to Lordosis in many aspects, but while Lordosis happens in lordotic curves, Kyphosis is a medical condition affecting the kyphotic curve in the Thoracic area - People with Kyphosis will have an abnormally excessive convex curvature of the area; A normal kyphotic curve will have a band between 20 to 45 degrees, but according to the medical definition - in case of Kyphosis, the spine curvature would be larger than 50 degrees, which could be determined through an X-Ray test[18].

Kyphosis can happen as a birth defect(Ex:spina bifida), but those cases are rare, and usually Kyphosis will appear later in life from various reasons; It could be as a side effect of other medical conditions such as metabolic problems,neuro-muscular conditions, bone diseases (osteoporosis, Scheuermann disease) or injury of the spine. It can also be a results of old age, weak muscles in the upper back or simply bad posture which can lead to deterioration of the spine curve[19] [18].
While most cases of Kyphosis are mild and only require routine monitoring and some exercises and physical therapy to increase muscle strength as a treatment, (or supporting braces for kids who are still growing) more severe cases can result in pain and discomfort, breathing difficulties and digestion or cardio vascular problem, and can require pain relief medicines and bracing[19].
In cases of extreme large curve (over 75 degrees), or if a bracing will not slow the progress of the curving, a surgery might be needed in order to fix the curve[18] (for example spinal fusion surgery, which is used to fuse together two or more vertebrae, in order for them to fuse together into a single bone[21]).

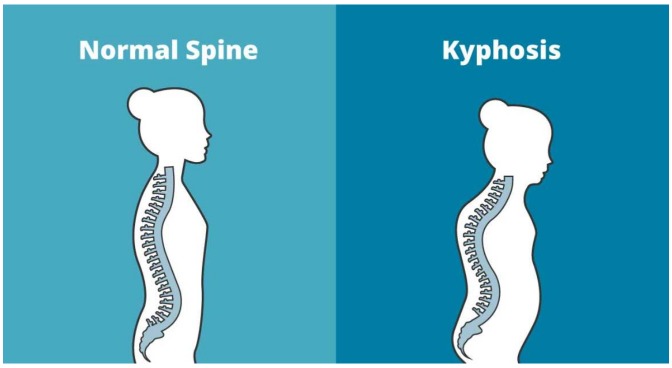

Figure 1.4: Example of Kyphosis[29]

Scoliosis can appear in both lordotic and kyphotic curves along the spine. When looking on a normal spine from behind it appear to be a straight line, but when looking from behind on a spine with scoliosis, it will appear to be in a "S" or "C" shaped, depend on which curves the Scoliosis affect.
The medical definition of Scoliosis is when a curve of the spine is over 10 degrees, and it can be measured by an X-Ray examination[23].
Unlike Kyphosis, Scoliosis can not be cause by bad posture. It does not have a known cause, and according to the American Association of Neurological Surgeons (AANS), over 80% of the Scoliosis cases are idiopathic and have no known reason[22].
Some of the reasons which are known and recognized are spine and back injuries, birth defects, neurological abnormalities (Ex:Cerebral palsy),physical problems in the spine (Ex:break down of spinal discs as a result of osteoporosis), or be hereditary and run in the family[22] [23]. Like in the cases of Lordosis and Kyphosis, mild cases of Scoliosis (up to 25 degrees of curvature) can be treated by regular checks and observations. More severe cases (25 - 30 degrees curv. or smaller curve which continue to grow) will be treated

with bracing, which usually won't fix the curve, but slow it done or stop it growing and support the back, and extremely severe cases (over 45 degrees or when using brace is not helping) will result in a surgery (Like in case of Kyphosis, spinal fusion surgery is common solution)[23].

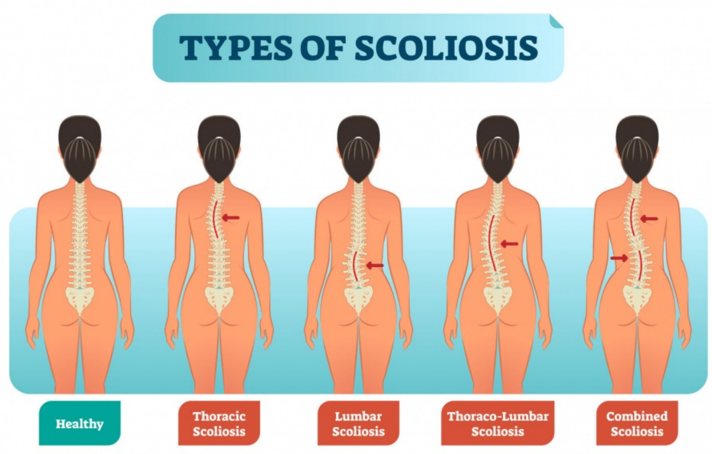

Figure 1.5: Different types of Scoliosis[44]

As for today, radiography (X-Ray test) considered as the 'gold standard' in diagnosis, evaluation and management of spinal deformities, especially in young age, when the body and bones are still growing and changing, and there's higher possibility that the curve will grow larger[48].
When it's come to the monitoring of gait and posture, they are important indicators of health, medical conditions such as diabetes complications, as well as a way to detect and predict the chances of falling in old people[42], and are common practice in rehabilitation, diagnosis and monitoring balance problems[4].
In this field, Optical Motion Capture systems (OMC) are considered as the 'gold standard' in the field of gait and posture analysis[2]. Those systems, usually combine with force platforms (which measure the ground reaction forces which results from standing or moving on the platforms) for balance analysis, allow not only visual feedback, but also able to locate the joints and analyze their movements, adding deeper level of observation. The OMC systems usually combined special cameras, as well as sets of reflective markers and special software. The types and number of cameras and software can vary between different systems and according to the customer needs, and the prices vary accordingly. The price range can start from around 100$ to set of markers[14], and can get up to 250,000$ for the multi cameras special sets[6], but the basic camera systems price range is between 1500$ to 8000$ usually[9] [6].

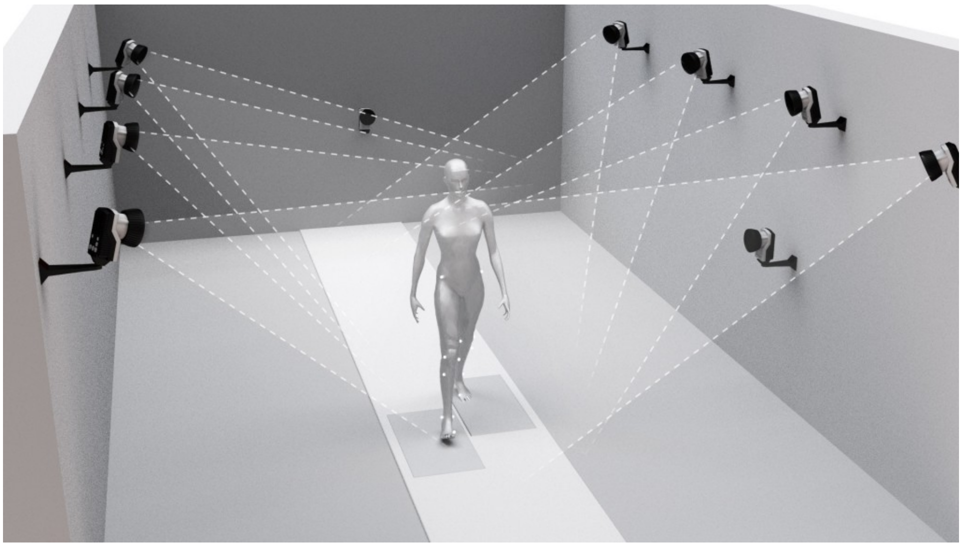

Figure 1.6: Example of gait analysis lab setup, include cameras, force platforms and markers[45]

The working principle of motion capture is "the process of recording real life movement of a subject as sequences of Cartesian coordinates in 3D space"[34].The systems use special equipment to reconstruct the object's posture,movements and body location in space, allowing better visualization of the movements of different body parts. And while it is possible to get feedback regarding movements by looking at it with a naked eye, some movements are too quick or subtle for the human eye to notice, and by using OMC technology, it is easier to capture those motions, and get better analysis of them[37], making this technology useful in many fields; from the entertainment field, where it used in 2D and 3D computer animation to create a better understanding of body movements in animated films, resulting in improved feeling of life and reality of the characters, or as an effective tool in the CGI (Computer-generated imagery) field, helping to create special effects and different scenarios and sets easily[35], in sport, where it allow to analyze the athletes motions and movements, in order to improve their results and performances, or in the gaming industry, where learning the way people moves, allow to design better and more realistic in-game characters, or in case of virtual reality field - allow the players to be part of the game themselves[38] [13].
The OMC systems are also useful in the engineering field, where it is used to design models and study their characteristics, or study the way a machine work[37], or in robotics, where understanding the way people, animals or objects move, helps to design stable and more efficient robots for different uses[36].

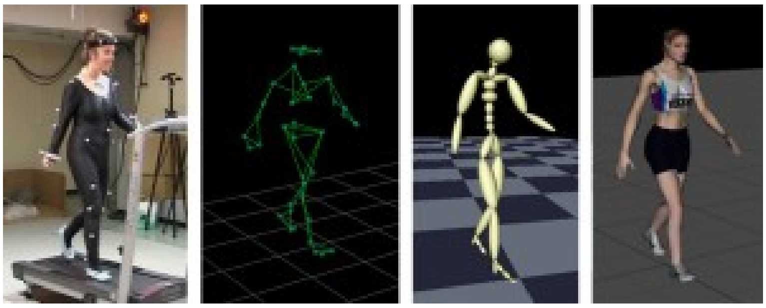

Figure 1.7: Example of use of OMC system in gaming[43]

Some of the main companies in the motion capture field today are VICON[13], QUALYSIS[12] and OptiTrack[9].
The two main technologies which being used in the OMC systems are the active method - using a pulsing LED as a marker, and the passive method - using markers coated in reflective materials.
The main concept of the OMC systems is to use cameras to track the reflective or LED markers and use it to compute the location of the part to which the marker is attached.
OMC Cameras which are working with the passive method will usually have an infra red (IR) LED device around the lens which will cast IR light into the space, which will be reflected back from the attached markers. An IR pass filter installed over the lens itself, allow the camera to detect and process the reflected IR waves in the frame.
With Cameras working by the active method, what is measured is not the reflected IR waves, but rather the IR light actively emitted by the LED[17].
While MKV2 is using the OMC passive method as a device, when regards on its use of optical properties, it referred to as an active sensor since it use its own light source for the active illumination of its surrounding[41].
Unlike the first version of the Kinect (MKV1) which use projection of pattern IR light dots and processing of their density to calculate the depth of different objects in its range, the MKV2 is using a Time of Flight (TOF) technology approach[40].
The main technological principle on which a 3D time of flight cameras are working, is illuminating their surroundings with a modulated light source (typically pulsed or modulated by a continuous-wave (CW) source), and then receive the reflected light back. The phase shift between the illumination and the reflection is then measured and calculates, based on the time passed and the speed of light, into distance. Usually, the illumination is done with a laser or LED operating in the near-infrared range (around 850nm) invisible to the naked human eyes. An imaging sensor designed to respond to the same spectrum receives the light and converts the light energy to an electrical current, which then transfer into a memory element (capacitor for example) which sum it together. a counter is connect to the imaging sensor, and stops its count once light is detected.[39].

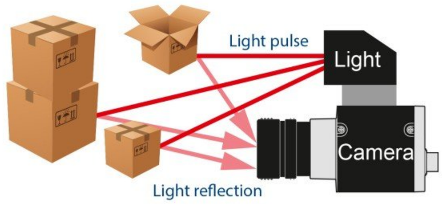

Figure 1.8: Basic principle of TOF cameras[20]

The MKV2 device is similar in its work principle to a TOF camera; It consist of two cameras, an RGB one and an infrared (IR) camera and the illumination of its surroundings is done by three IR laser diodes which sending modulated IR light beams, which periodically turned on and off,a method which help to reduce ambient lighting noise[40].

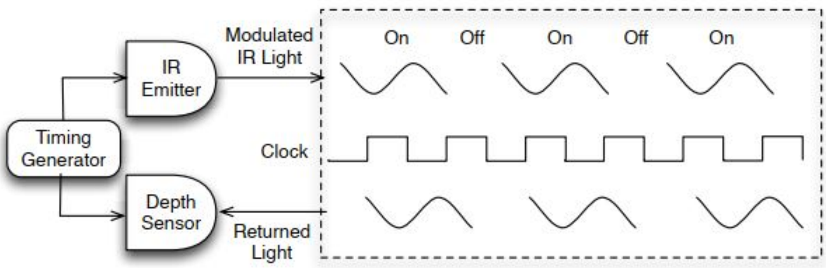

Figure 1.9: How the MKV2 use time-of-flight method for depth sensing[40]

Infrared (IR) camera resolution	512 × 424 pixels
RGB camera resolution	1920 × 1080 pixels
Field of view	70 × 60 degrees
Framerate	30 frames per second
Operative measuring range	from 0.5 to 4.5 m
Object pixel size (GSD)	between 1.4 mm (@ 0.5 m range) and 12 mm (@ 4.5 m range)

Figure 1.10: Technical data of the MKV2[41]

The original purpose of the Kinect when it was first release in 2010 was to work with Xbox gaming consoles, allowing the players to interactively control the console by their body movements and gestures, using the device depth sensor and its ability to estimate the human skeleton and trace joint movements.
In 2011, Microsoft release a software development kit (SDK) for the Kinect device, which allow users to develop their own motion tracking applications beyond the Xbox games. Since then, the Kinect was used in various fields;

From application to train manual workers how to lift weight correctly, by giving them feedback on their skeletal position in real time, or in the fields of Robotics, where the Kinect is used for navigation and remote controlling (navigating a robot using hand gestures for example)[40].
The ability to create new applications for the Kinect has contribute widely to the clinical and medical fields as well;
Some examples of applications which are using Kinect motion capture and skeletal tracking in the medical fields are An interactive game-based rehabilitation tool for adults with neurological injury, an interactive rehabilitation system for therapy for disabled children, or a a Kinect-based game which is used for stroke rehabilitation, helping the patients to regain their control in the parts or functions which were damaged by the stroke. The use of the Kinect give the therapy and rehabilitation process the feeling of a game, encourage people to continue the process.
The Kinect is also used for fall detection and prevention in elderly people. Examples of application in this field are fall detection based on Kinect skeletal data, an application for fall prevention in hospital ward environment and detecting falls events on stairways[40].
The main difference between most of the Kinect applications existing today to my proposed idea is that while most of the applications use the abilities of the Kinect to track the joints, skeleton and motion in general, my application is using the infra red sensor in the Kinect in order to recognize the markers and calculate parameters from their locations with an un-moving subject.
The reasons I've chose to work with reflective markers and not use the Kinect depth sensor and skeleton tracking abilities firstly that the markers have higher accuracy in this case, since they are placed to the same anatomical points without moving or changing during the different measurement positions, and secondly is that it is harder to locate the spine with a depth sensor, which only gives the general form of the body.

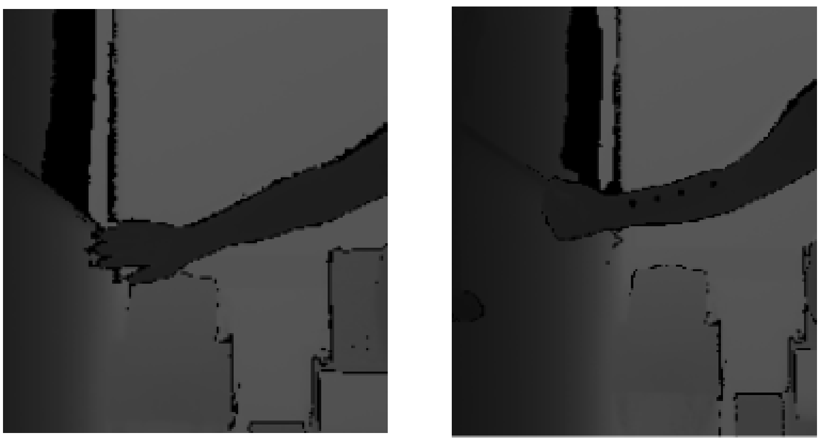

Figure 1.11: Images taken from the Kinect depth sensor stream, with and without markers

1.2 Aims of the thesis

The first main aim of this thesis work is to create an algorithm in Matlab SW which will be able to detect the location of reflective markers placed in six different anatomical points along the spine, using a Microsoft Kinect V2 camera, and calculate the angles between each adjacent markers. Additional aim for this algorithm is to connect to a pair of Nintendo Wii Balance Board (WBB) platforms, collect the data from their sensors, and use the received data to calculate the center of pressure (COP) for each feet, as well as the center of gravity (COG) of the measured person and the percentage of the weight acting on each feet out of the total weight of the subject.
The second main aim of the thesis is to find if exist a correlation between the alignment of the spine, the weight distribution across an individual's feet and the center of pressure of each feet, using various statistical tools as part of the Matlab algorithm.

Chapter 2
Methods

In this thesis work, a Microsoft Kinect V2 camera was used in order to find six anatomical points marked by reflective markers along the spine. Also a pair of Nintendo Wii Balance Boards was used to find the center of pressure and weight for each foot. All calculation and data analysis was done in Matlab SW, version R2018a. The measurements were done on healthy adults human subjects and were approved by FBME CTU Institutional Ethical/Review Board (Approval form in appendix A).

2.1 Subjects

The measurements were performed on 15 healthy volunteers; 6 females and 9 males, age 24.5 +/- 6.5 years, height 167 cm +/- 15 cm. All are students and staff members of CTU -FBME in Kladno, Czech Republic.

2.2 Equipment

The following equipment was used for the measurements and data processing:

- A Microsoft Kinect V2 camera + adapter (Microsoft Co., Washington, United States)
- Two Nintendo Wii Balance Boards RVL-021 (Nintendo Co. Ltd., Japan), connected to a computer via Bluetooth connection
- Six standard reflective markers with a diameter of 1.5 cm (stuck to the body with double sided glue)
- Matlab R2018a (MathWorks, Massachusetts, United States)
- Two 'WiiLab' libraries (32 and 64 bits), originally designed for Nintendo Wiimote drivers[46]
- Three supplementary add - ons which required for the Kinect to work properly: Kinect Studio V2.0, Kinect for Windows SDK 2.0 and KinectRunTime.

2.2.1 Calibration of the WBB platforms

For calibration of the WBB, the offsets of both platforms were taken first and then subtract from each platform accordingly before the subject's measuring process begun.
However,when using the 'WiiLab' libraries to retrieve the data from the sensors inside the platforms, the values received (BBVals in the code) are 4 times higher than the correct values. This could be a result of library calculation error and multiplication by the number of the sensors in a platform (4). This problem is solved during the calibration and along the data collection process by dividing the BBVals received by 4 before using them to calculate the COP and weight percentage.

2.2.2 Equipment set - up

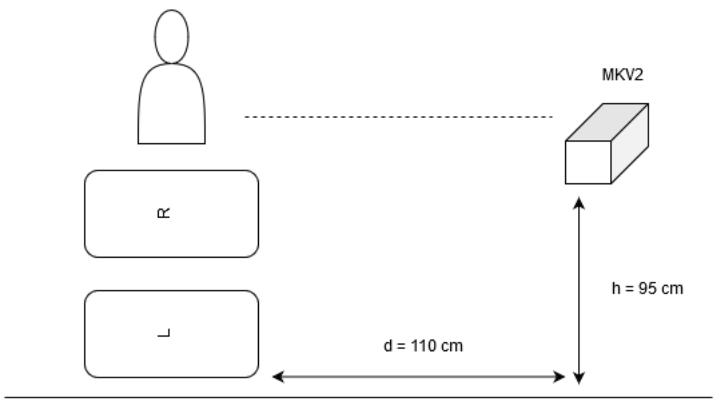

Figure 2.1: Scheme of the Kinect camera and platforms

Figure 2.2: How the subjects stand on the platforms

Microsoft Kinect V2 camera

The camera was positioned facing the back of the subject. The height of the camera from the ground was 95 cm, and its distance from the measured subject was 110 cm. However, those measures were adjust accordingly when needed so that the camera will recognize all of the six markers clearly in every frame.

Figure 2.3: Kinect V2 camera and its adapter were used for the measurements[27]

Nintendo WBB

The two Balance boards were positioned differently for each measurement position (detailed information in section 2.3 Measurement Procedure).

Figure 2.4: Two Microsoft Wii BB platforms were used for the measurements[28]

Markers

Six standard reflective markers, made from infra red (IR) reflecting materials, (1.5 cm in diameter) were positioned in six anatomical points along the subject's spine (C7,T2,T7,L1,L3,L5).
The markers location was chosen according to the IOR multi - segment trunk model which is part of the IOR gait analysis protocol[11]. The placement of the markers allow for good coverage of the spine from the end of the cervical curve (C7) through the thoracic curve (T2/7) and all along the lumber curve (L1/3/5), providing detailed information on the spine's alignment at each point.

The markers are covered in IR reflecting material, which causes the IR light beams emitted from the Kinect to deflect from the markers and to bounce away instead of returning into the Kinect's depth sensor, creating 'black holes' of unrecognized pixels in the frames the device recognizes. The algorithm is then able to locate and isolate the holes in the frames by using a mask created with the 'fspecial' function with Gaussian distribution followed by the 'conv2' function. Finding the center's coordinates is then done by the 'regionprops-centroid' command.

Figure 2.5: Six infra red reflecting markers were used for the measurements[26]

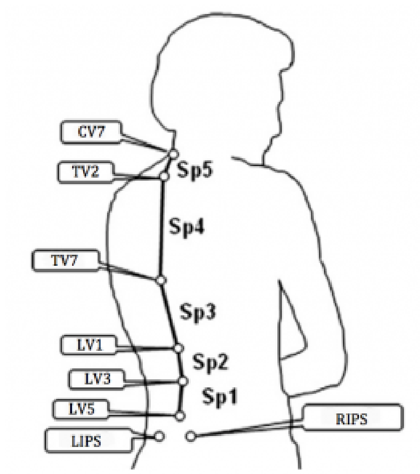

Figure 2.6: The location of the markers according to the IOR model[24]

2.3 Measurement procedure

During the measurements, each subject was standing without moving, and with head straight and looking forward in four different positions on the WBB platforms, each position was held for 60 seconds.
The positions were the following:

- Platforms positioned on the floor next to each other (exist 77 mm gap between them), subject is standing in the middle of each platform. Distance between the middle of one feet to another is 315 mm.
- The platforms are positioned with wider gap between them. Distance between the middle of one feet to another is 650 mm.

- The left platform is positioned in front of the right platform. Distance between the middle of one feet to another is 240 mm in the horizontal direction, and 433 mm in the vertical direction.

- The right platform is positioned in front of the left platform. Distance between the middle of one feet to another is 240 mm in the horizontal direction, and 433 mm in the vertical direction.

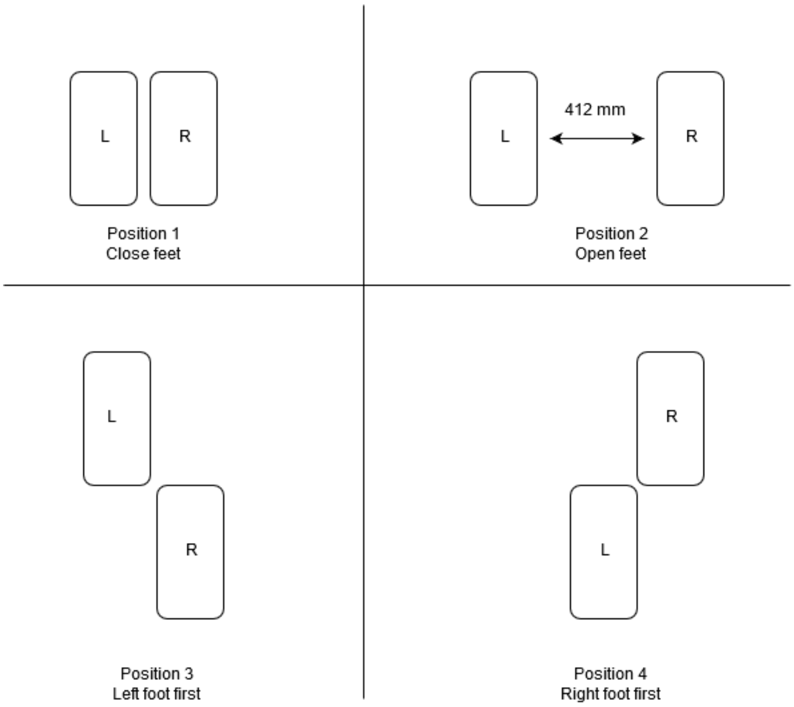

Figure 2.7: Scheme of the different platforms positions

2.3.1 Data collection

The Nintendo platforms are connected to a computer via a Bluetooth connection, allowing the software to receive data from the 8 sensors located at the corners of each platform. The Kinect camera is connected to the computer with a special Xbox Kinect adapter, allowing the computer to get the video transmission from it. The data from the sensors and the camera is sampled for 60 seconds, at a sampling frequency of 20 Hz. Those samples are then processed by a designated Matlab script, which computes the subject's center of pressure (COP), center of gravity (COG) and weight distribution between the feet. At the same time, the frames received from the camera are being processed by the algorithm to find the center of each reflective marker shows in them and then using the center's coordinates to calculate the angle between each adjacent markers.

2.3.2 Equations for calculating COP and COG coordinates and angles between adjacent markers

The following equations were used in the script to calculate the center of pressure X and Z coordinates for each platform and the X and Z coordinates of the total center of gravity, as well as to calculate the angles between the markers. $\frac{433}{2}$ is half the length of a platform, $\frac{238}{2}$ is half of the platform's width, $S_1 - S_4$ are the values from the sensors on the left platform and $S_5 - S_8$ are the values from the right platform's sensors. All the values are in millimeters (mm).
In equations **2.5** and **2.6** M_{LX} and M_{LZ} are the moments in the X and Z direction in the left platform. and M_{RX} and M_{RZ} were calculated in a similar way with the data from the right platform's sensors.
Offsets were added to the calculations in both X and Z directions, according to the change in the platforms position. The moments were then used in equations **2.7** and **2.8** to calculate the COG values.
In equation **2.9** P_{12} and P_{13} are the vectors between the markers coordinates.

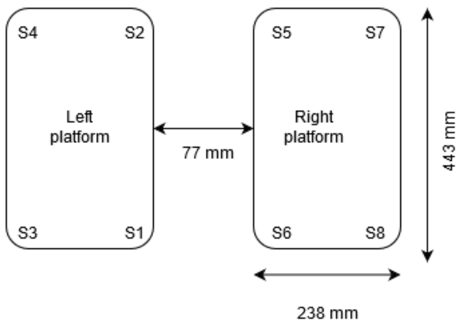

Figure 2.8: Scheme of the sensors placement and the platforms scale

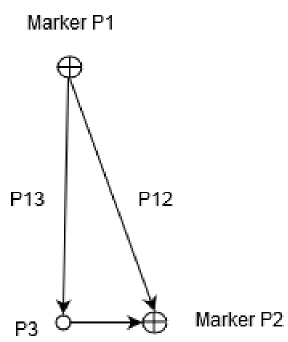

Figure 2.9: The vectors were used to calculate the angle between each adjacent markers

$$COPL_X = \frac{433}{2} \cdot \frac{-S_1 + S_2 - S_3 + S_4}{S_1 + S_2 + S_3 + S_4} \tag{2.1}$$

$$COPL_Z = \frac{238}{2} \cdot \frac{S_1 + S_2 - S_3 - S_4}{S_1 + S_2 + S_3 + S_4} \tag{2.2}$$

$$COPR_X = \frac{433}{2} \cdot \frac{S_5 - S_6 + S_7 - S_8}{S_5 + S_6 + S_7 + S_8} \tag{2.3}$$

$$COPR_Z = \frac{238}{2} \cdot \frac{-S_5 - S_6 + S_7 + S_8}{S_5 + S_6 + S_7 + S_8} \tag{2.4}$$

$$M_L X = (S_1 + S_2 + S_3 + S_4) \cdot (COPL_X - Offset_X) \tag{2.5}$$

$$M_L Z = (S_1 + S_2 + S_3 + S_4) \cdot (COPL_Z + Offset_Z) \tag{2.6}$$

$$COG_X = \frac{M_{LX} + M_{RX}}{S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8} \tag{2.7}$$

$$COG_Z = \frac{M_{LZ} + M_{RZ}}{S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8} \tag{2.8}$$

$$Angle = \arccos\left(\frac{P_{12} \cdot P_{13}}{|P_{12}| \cdot |P_{13}|}\right) \tag{2.9}$$

2.3.3 Methods for data analysis

After receiving the calculated left and right COP, weight distribution and angles between the markers from each sample, the Matlab script then analyzes it, calculating the Mean, Median and Standard deviation of the measured data, and visualizing the information to allowing recognition of trends and changes.
For statistical analysis, for each subject, in every position, the means and standard deviation of the following parameters; X and Z coordinates of center of pressure left and right and center of gravity, as well as the weight distribution in both feet and the angle C7-L5 each subject's in every position were tested for normality (**alpha** = 0.05) using the Shapiro-Wilk test which found that the data is both from normal and non - normal distribution. Therefore an Wilcoxon rank sum test was performed with alpha = 0.05 with the null hypothesis H_0 claiming that the data from the two populations have the same continuous distributions with equal medians.

Chapter 3

Results

The following graphs and tables in this chapter details the results of the measurements that were taken, and help to visualize the subjects data, such as the COP, COG, and the weight distribution between the feet over the different measurement positions.

The tables depict statistical analysis provided by the algorithm COP measurements are in relation to each independent board, while the COG measurements are in relation to a unified coordinate system including both boards, with the offsets change according to the measurements positions. In essence, COP (0,0) is the center of the relevant board, while COG (0,0) is the middle point between the two boards, i.e the center of the test set-up. The confidence ellipse added to the example scatter plots are of 95% confidence. The larger their area, the less stable the subject was. The statistical data was calculated with the Matlab 2018a SW.

3.1 Figures and tables

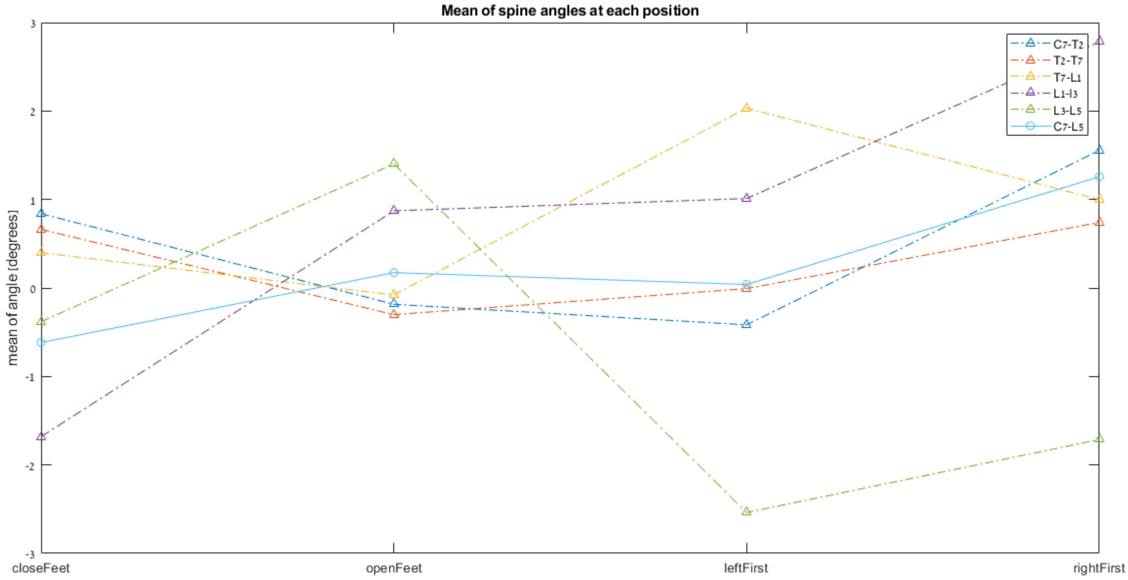

Figure 3.1: Total means of angles across all subjects and positions

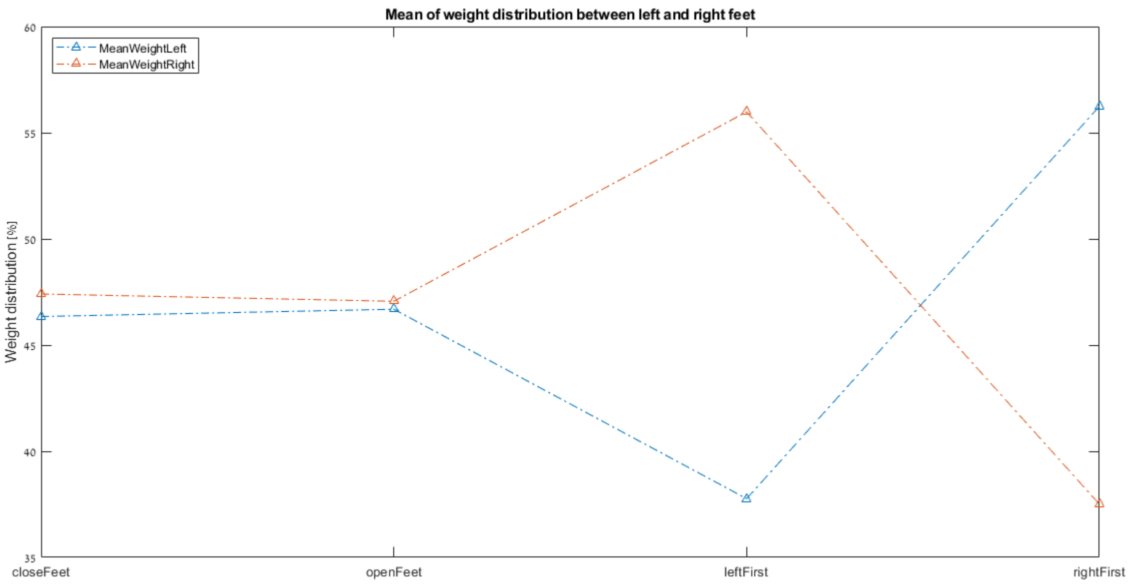

Figure 3.2: Total means of weight distribution across all subjects and positions

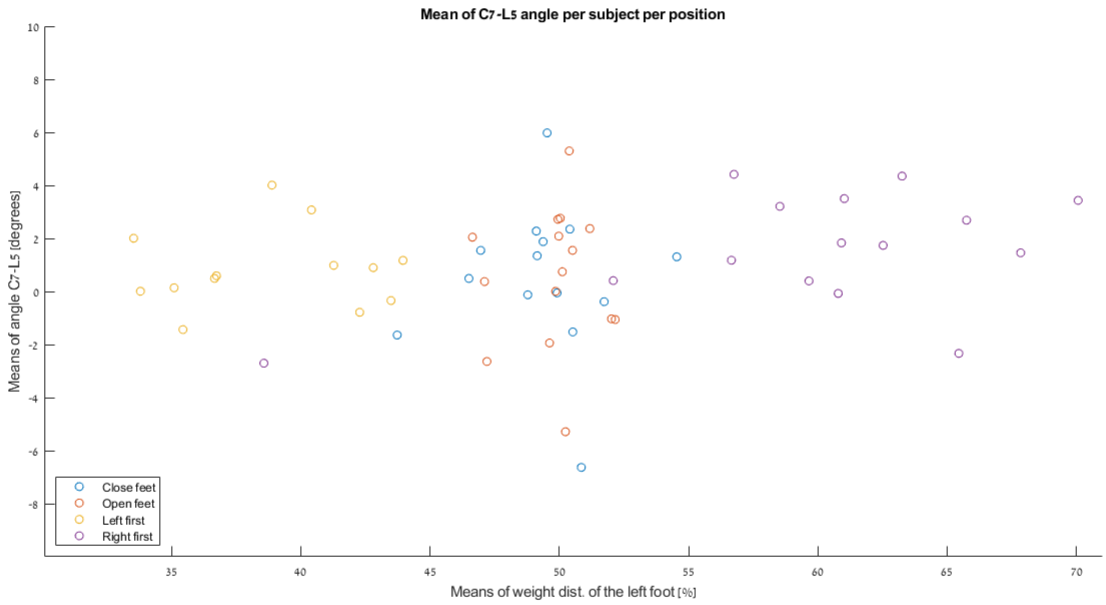

Figure 3.3: Individual means and weight distribution of the left foot across all positions

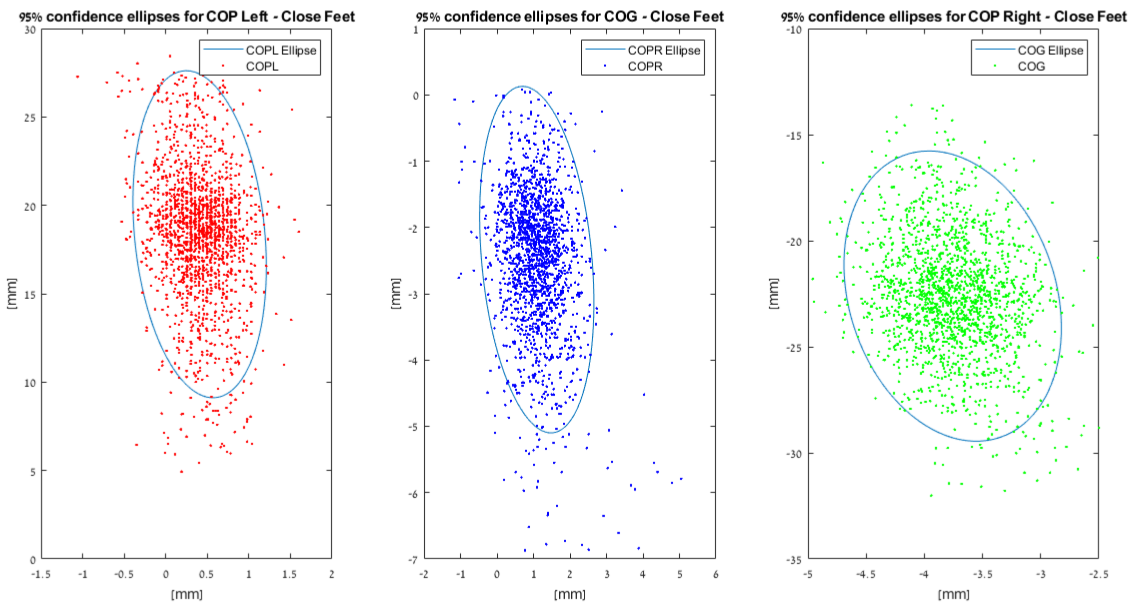

Figure 3.4: COP and COG of a single subject - w/close feet

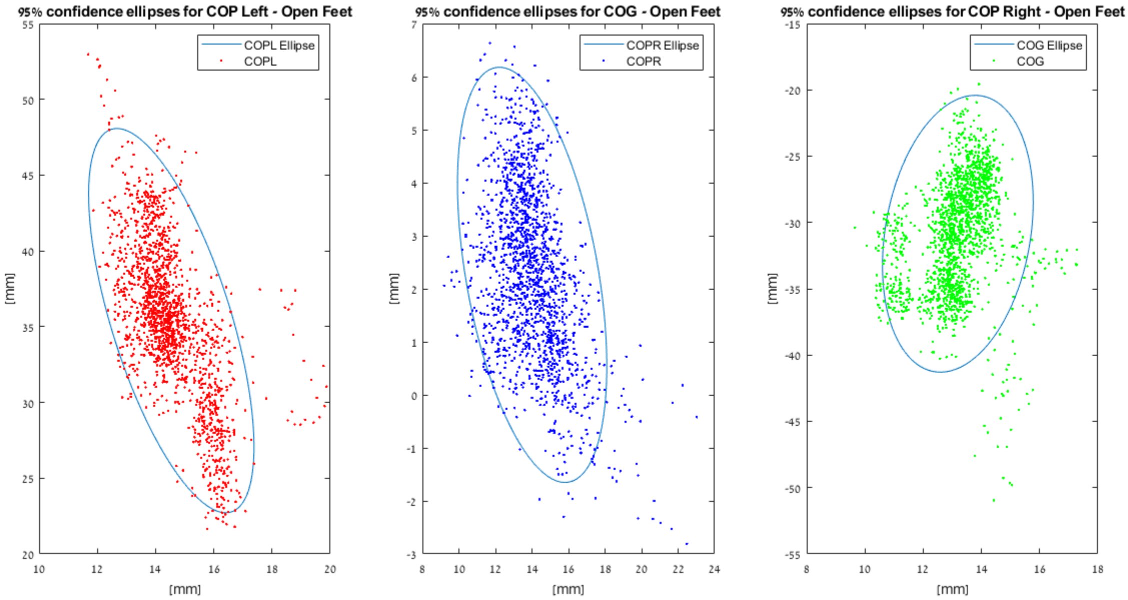

Figure 3.5: COP and COG of a single subject - w/open feet

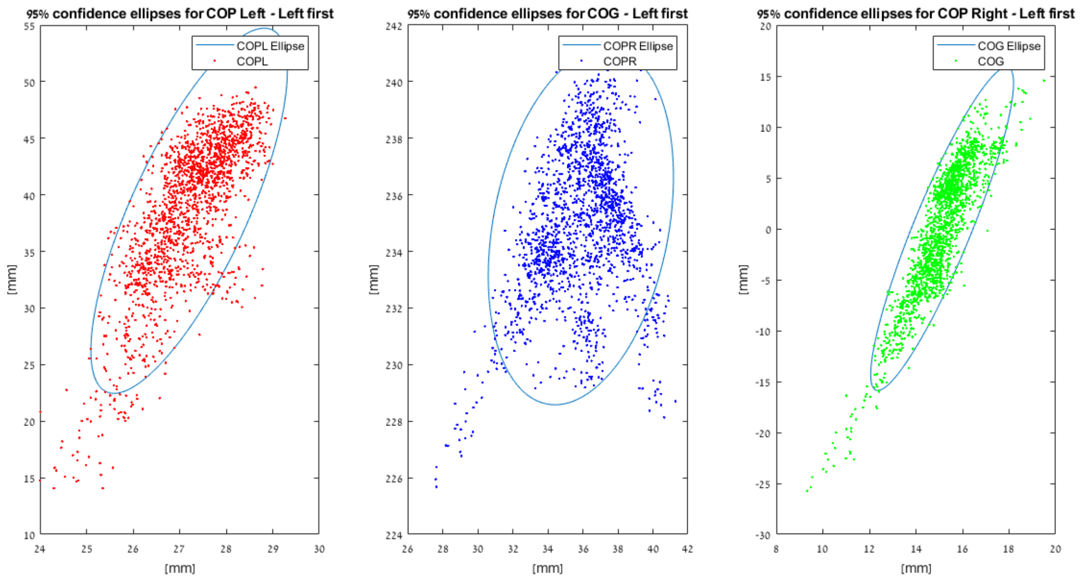

Figure 3.6: COP and COG of a single subject - w/left foot first

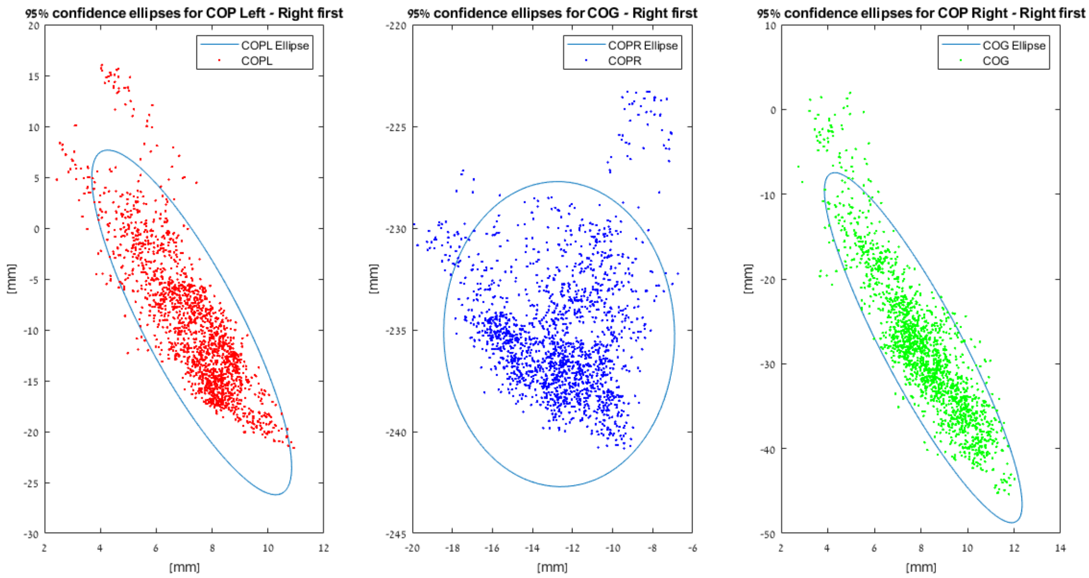

Figure 3.7: COP and COG of a single subject - w/right foot first

Parameters	Means and (S.D) values			
	CF	**OF**	**LF**	**RF**
$COPL_X$	-3.1 (7.63)	7.06 (11.98)	9.31 (12.22)	1.87 (8.21)
$COPL_Z$	14.53 (31.07)	15.68 (32.39)	15.71 (41.27)	1.46 (21.41)
$COPR_X$	1.59 (9.31)	6.17 (10.85)	7.86 (7.93)	14.01 (6.24)
$COPR_Z$	-24.23(21.74)	-26.75(14.62)	-4.56(16.96)	-46.59(22.51)
COG_X	1.17(9.75)	7.81(14.38)	31.67(22.13)	-16.96(17.54)
COG_Z	-5.16(12.04)	-5.61(17.46)	120.11(119.3)	-134.35(112.46)
Weight $\%_L$	49.43(2.46)	49.81(1.64)	40.28(7.87)	59.99(7.52)
Weight $\%_R$	50.57(2.46)	50.19(1.64)	59.71(7.87)	40.01(7.52)
Angle C7-L5	-0.26(3.97)	0.53(2.63)	-1.14(5.58)	1.57(2.17)

Table 3.1: Table presenting the means and (S.D) of the different measured parameters for each position (Close feet(CF), Open feet(OF), Left first(LF), Right first(RF)) COP and COG values are in coordinates across the platforms (COG with offset) and the angle is in degrees

Parameters	**p value of parameters in relation to C7-L5 angle**			
	CF	**OF**	**LF**	**RF**
$COPL_X$	**0.2499**	**0.2658**	0.0273	**0.5844**
$COPL_Z$	**0.0732**	0.0248	**0.0932**	**0.6373**
$COPR_X$	**0.3554**	0.0436	0.0363	0.0007
$COPR_Z$	0.0019	0.0001	**0.3361**	0.0006
COG_X	**0.1931**	**0.1089**	0.0007	0.0006
COG_Z	**0.3361**	**0.3753**	0.0301	0.0001
Weight $\%_L$	0.0002	0.0005	0.0006	0.0009
Weight $\%_R$	0.0002	0.0005	0.0006	0.0009

Table 3.2: Calculated p values for each parameter in comparison to the angle C7-L5. Bold numbers indicate rejection of the null hypothesis

Chapter 4

Discussion

The drive of this thesis work was to check for correlation between spinal alignment, center of pressure (COP), center of gravity (COG), and weight distribution between the feet in healthy adults.
To answer this question, a Matlab algorithm was created, aimed to collect data from both a Microsoft Kinect V2 and two Nintendo Wii platforms(WBB), analyze it, and calculate the COP, COG, weight distribution, and spinal alignment of the subjects.
While in table **3.1** we could see some general trends regarding the mean and standard deviation of the center of pressure, center of gravity, weight distribution and the angle C7-L5, which is along the spine; we can see that while standing with closed or open feet, the angle is very small and insignificant - less than one degree, but when standing with left or right foot first, the angle is about one degree higher, and inclined towards the leading foot, showing a slight alignment of the spine towards the foot in the front. We can also observe in the cases of right or left foot in front that in both cases, more weight (about 20%) was put on the hind leg, while in the cases of closed and open feet, the weight distribution was mostly equal.
However, as can be seen in table **3.2**, It can not be stated that exist an clear correlation (**p>0.05**) between the center of pressure, center of gravity or weight distribution to the alignment of the spine, and therefore I will have to reject my original hypothesis regarding the connection between those groups of data.
A possible reason for the results is that the measurements were performed on healthy subjects only, with good balance and posture, and therefore any changes in the spine alignment during the different types of stance where minor and did not affect their posture in a noticeable way, and that a similar measurements on subjects with spinal problems will might lead to different results.

While unlike various projects which use the Kinect ability of skeleton and body recognition as a marker-less tool to monitor and encourage private people to continue their therapy or rehabilitation exercises at home[40], the system presented in this work would be less suitable for private use. The markers need to be placed by someone professional who can apply them to the same spots each time for better tracking. And although it failed to prove a correlation, the algorithm and the system the Kinect and the WBB were checked before[5] [4] and found to achieve similar results to force platforms and professional OMC systems[5] would not suit medical facilities which specialize in balance and gait analysis, and needs more accurate devices, but could be a useful tool in non-specialize medical facilities, such as GP (General practitioner), which usually lack the equipment for postural analysis, since it is mostly expensive and not easy to manipulate. Also,GP have returning patients which come for usual check ups, and usually will belong to the same infirmary for many year, allowing consistent monitoring of their balance and posture and can enable to recognize postural deterioration or change at its beginning.

The location of the markers in his work was chosen according to the IOR segmenting model[24] but the markers can be placed according to the curve which needs to be monitored, especially in cases of Lordosis[16], Kyphosis[18] and scoliosis[22], which usually require only routine monitoring for the mild cases, especially with young patients which are still growing. The use of the balance boards in the system can be useful as well on this cases, since the tendency to unequal body weight distribution is one of the compensatory mechanisms in scoliosis[50].

During the measurement process I have encounter some complications; While working on the software, there were some unforeseen complications, for example,I could not get my computer to work with the libraries that connect between the platforms and the computer, no matter what I have tried – working with different versions of Matlab, trying different .Net frameworks or working from another computer with another Bluetooth driver, nothing solve it and I kept getting the following error code – 0xe0434352 before my Matlab would crash.
However, it was also impossible to perform the measurements on Mr. Volf's computer, since his Windows version is Windows 7, and the Kinect is able to work with Windows 8 and onward only.
As those are technical problems, I had agreed with my supervisor to temporarily using other professor's laptop when it was free, as well as one of the computers in the faculty lab between classes.
Those limitations had slowed my measurement process, but eventually I was able to perform the required measurements. I believe that the problem with my computer and the platforms could due to difference of windows versions; while I've tried to work with windows 8 and windows 10, which are able to work with the Kinect device, as said, my supervisor have windows 7 on his laptop, and since the libraries I have tried to work with are dated to back to 2007 [46], they might not work well with later version of windows.
As for the second problem - a later version of windows will most probably solve it.

Chapter 5

Conclusion

The aims of this thesis work were to create an algorithm in Matlab SW which will be able to detect the location of reflective markers placed in six different anatomical points along the spine, using a Microsoft Kinect V2 camera, and calculate the angles between each adjacent markers, as well as to connect to a pair of Nintendo Wii Balance Board (WBB) platforms, to collect the data from their sensors, and to use the received data for calculations of the center of pressure (COP) for each feet, as well as the center of gravity (COG) of the measured person and the percentage of the weight acting on each feet out of the total weight of the subject, and to find if exist a correlation between the alignment of the spine, the weight distribution across an individual's feet and the center of pressure of each feet, using various statistical tools as part of the Matlab algorithm; While I was able to successfully build the algorithm and to measure and calculate all the planned data, The results of the work did not show an indication for a clear correlation between the parameters (p value>0.05) and I had to reject this hypothesis.
However, I do believe the combination of the Kinect V2, Nintendo WBB and the reflective markers could be a useful , inexpensive and easy to transport tool to monitor posture and spine alignment, and can be used along with mine or other's algorithms and applications to give a direct and clear feedback regarding the person's stance.

Appendix A

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Ortop Traumatol Rehabil. 2012 Nov-Dec;14(6):525-35
Accessed on 03.05.2019

A.1 Ethics documentation

Application for approval of a bachalore thsis by FBMI CTU Institutional Ethical/Review Board

Name of the project: Correlation between weight distribution and center of pressure with spinal alignment using Nintendo Wii Balance Boards and Kinect V2 camera

Project leader (Name, Study place, E-mail): Noa Bar
Faculty of Biomedical Engineering, CTU,Kladno
Noa.bar07@gmail.com

Brief description of the project (up to 100 words): The goal of this work is to create software solution in Matlab which will enable to check for correlation between the weight distribution across an individual's feet and center of pressure to spinal alignment. In order to get the required data the software solution will use two Nintendo Wii Balance boards and one Kinect V2 camera. The use of IR camera, together with reflective markers, which would be attached to the spine with double sided tape, will provide a reliable way to measure the subject's spinal position. Test of the software solution on a set of 20 probands holding four different postures (standing with close feet, with feet wide apart, with the right foot in front of the left and with the left foot in front of the right) and will evaluate statistically.

Project type: Diploma thesis

List of attached documents:
- Informed consent incl. information for the subject of the evaluation
- Syllabus of the project

In Kladno on ________________________

____
signature of main researcher

Vyjádření souhlasu etické komise FBMI ČVUT

FBMI CTU Institutional Ethical/Review Board approval

Projekt byl schválen etickou komisí FBMI ČVUT dne: **platný do:**
pod číslem:

Etická komise FBMI ČVUT v Praze, ve složení Mgr. Martina Dingová Šliková (předsedkyně), RNDr. Táňa Jarošíková, CSc., MUDr. Radek Matlach, prof. Ing. Karel Roubík, Ph.D., a Ing. Lucie Šedzmáková, zhodnotila předložený projekt a neshledala žádné rozpory s platnými zásadami, předpisy a mezinárodními směrnicemi pro provádění biomedicínského výzkumu zahrnujícího lidské účastníky nebo laboratorní zvířata.

Řešitel projektu splnil podmínky nutné k získání souhlasu etické komise.

V Kladně dne

____
razítko etické komise FBMI ČVUT

____
podpis předsedy etické komise

Informed consent

And information for the subjects

Name of the project: Correlation between weight distribution and center of pressure with spinal alignment using Nintendo Wii Balance Boards and Kinect V2 camera

Main researcher, co-researcher and their workplace: Ing. Petr Volf, Noa Bar – CTU in Prague, FBMI, Faculty of biomedical engineering.

To whomever it may concern,

The project 'Correlation between weight distribution and center of pressure with spinal alignment ' is a diploma thesis project carried out at FBMI CTU. This project deals mainly with the development and testing of a new Matlab algorithm which will be use to calculate, with the help markers, which would be attached to the spine with double sided tape, and an infra red camera, the allignment of the spine.

An existing algorithm from previous project will be used as well to calculate the subjects center of pressure for each feet. Both data sets would be then compared and statisticaly analyzed.

Measurements are performed on healthy volunteers (subjects) aged 18-50, especially from the FBMI students in the estimated maximum of 20 subjects. Within each measurement round, volunteers will hold four different positions, while standing on two Wii balance board platforms.

The standing positions would be:

1. Standing with close feet
2. Standing with feet open wide
3. Standing with their right foot in front of the left
4. Standing with their left foot in front of the right

The expected duration of round of measurements per volunteer is up to 20 minutes.

The entire measuring procedure is a completely safe and non-invasive method for measuring quantities such as center of pressure and location of the markers, and no side effects or risks are described. Data will be processed in MATLAB software.

No conclusions about your health status will be drawn from the measured data.

Participation in the experiment is entirely voluntary, without any reward. At the same time, no financial expenses for the subjects are expected.

Informovaný souhlas
a informace pro subjekt hodnocení

Název projektu: Korelace mezi rozložením hmotnosti a centrem tlaku s tvarem páteře za využití stabilometrických plošin Nintendo Wii Balance Board a kamery Kinect V2

Hlavní řešitel, spoluřešitel a jejich pracoviště: Noa Bar, Ing. Petr Volf – ČVUT v Praze, FBMI, Katedra biomedicínské techniky.

Vážený probande,

Projekt hodnocení korelace mezi rozložením hmotnosti a centrem tlaku s tvarem páteře je bakalářskou prací na FBMI ČVUT. Tento projekt ze zabývá zejména návrhem a testováním nových algoritmu v prostředí Matlab, které umožní, za využití markerů umístěných na páteř pomocí oboustranné lepicí pásky a infračervené kamery, tvar páteře.

Dále budou použity algoritmy z předchozího projektu pro potřeby určení centra tlaku pod oběma chodidly. Data z obou metod budou následně porovnány a statisticky zhodnoceny.

Měření bude probíhat na zdravých dobrovolnících (probandech) věku 18-50 let, především z řad studentů FBMI o celkovém počtu 20 probandů. V průběhu měření budou probandi zaujímat čtyři pozice na dvojici stabilometrických plošin Wii Balance Board.

Jedná se o pozice:

1. Stoj s nohama u sebe
2. Stoj s nohama od sebe
3. Stoj s pravou nohou před levou
4. Stoj s levou nohou před pravou

Předpokládaná časová náročnost měření na jednoho probanda je cca 20 minut.

Celý průběh měření je zcela bezpečnou a neinvazivní metodou měření centra tlaku a lokalizace markerů bez vedlejších účinků a rizik. Data budou zpracována v prostředí Matlab.

Z naměřených dat nebudou vyvozovány jakékoli závěry o Vašem zdravotním stavu.

Účast na experimentu je zcela dobrovolná, bez nároku na jakoukoliv odměnu. Zároveň se nepředpokládají žádné finanční výdaje probanda.

Podepsáním tohoto písemného informovaného souhlasu souhlasíte s tím, že hlavní řešitelé a etická komise budou mít přímý přístup k původní klinické dokumentaci za účelem ověření průběhu anebo údajů souvisejících se studií, aniž dojde k porušení důvěrnosti informací o Vaší osobě, v míře povolené právními předpisy. Záznamy, podle nichž lze identifikovat probanda, budou uschovány jako

Sylabus of the research project

A: Basic data on the research project:	
Project title: Correlation between weight distribution and center of pressure with spinal alignment using Nintendo Wii Balance Boards and Kinect V2 camera	
Type of research: interventional	
Subjects: adult humans	
Aim of the project: The aim of this project is to develope a MATLAB algorithm which , together with markers and an infra red camera, will allow to calculate the spine alignment of the subjects, and compare it to the weight and center of pressure (COP) of each feet.	
Benefits of the project in the technical, diagnostic, therapeutic, medical or individual assessment area: Finding correlation between spine alignment and uneven COP distribution between the feet could help in early recognition of posture problems and and an early tratment as a result. The MATLAB algorithm can help make the posture checks more accessible and common use.	
B: Characteristics of the clinical trial subjects:	
Number: 20	*Age range:* 18 to 50 years
Gender: males and females	*Method of recruitment:* volunteering on request
Participation fee: none	*Other:*
Duration of the whole project (from - to): 18th of February 2019 – 22nd of May 2019	*Duration for one subject*: 20 minutes
Description of subject handling, description of intervention, sampling, etc.: Each subject will be standing on two Nintendo Wii balance boards – one feet in the center of each platform, with markers on different positions of their back. They will then undergo measurements in the following types of postures – standing with feet close, standing with feet wide apart, standing with right foot in front, and standing with left foot in front.	
The project differs from standard daily practice: YES *If yes, describe the differences:* The measurement process will require standing on flat platforms, while staying as still as possible for longer periods than usual (4 standing positions, as stated above, for 60 seconds each time)	
Possible risks, difficulties and difficulties for the subject of assessment (including ethical): Chance of risk is practically zero	
How does the safety of the test subject ensured: No special security needs to be provided	
Who will bear the cost of compensation in case of damage to the subject of the assessment: FBMI CTU	

In Kladno on ____________________ ____________________________

Main researcher signature

A.2 Code Samples

```
% Parameters set up:
% Duration of measurement: 60 seconds
% Frequancy of measurement: 20 Hz

bb1 = actxserver('WiiLab.WiiLAB');
bb1.Connect();
bb2 = actxserver('WiiLab.WiiLAB');
bb2.Connect();
clearvars -except bb1 bb2

% Server creation and connection:


%% Calibration
OffsetL = bb1.GetBalanceBoardSensorState()/4;
OffsetR = bb2.GetBalanceBoardSensorState()/4;

%%

daysToSec = 24*3600;     % convert from days to seconds
startTime  = daysToSec*datenum(datetime('now'));
setupSelector = 4; % 1 = closed, 2 = open, 3 = left, 4 = right
%  = inputer();
subjectNumber = 16;

% Kinect connection
vid2 = videoinput('kinect', 2);
triggerconfig(vid2, 'manual');
start(vid2);

% Preallocate vectors for calculation:
angleVec = zeros(6);
centroidVec = zeros(12);
PlatformTime = zeros(1);

j=1;
PlatformTime(j,:)=  0;

% Main loop
while PlatformTime(j,:)<60
j=j+1;

% WBB Part
```

```
PlatformL(j,:) = (bb1.GetBalanceBoardSensorState()/4)-OffsetL;
PlatformR(j,:) = (bb2.GetBalanceBoardSensorState()/4)-OffsetR;
PlatformTime(j,:) = daysToSec*datenum(datetime('now'))-startTime;
PlatformTime = round(PlatformTime,3);

%% Preallocate vectors for calculation:


% Kinect Part

frame = getsnapshot(vid2);

[angleVec,centroidVec] = getAngles(frame);

angleMatrix(j,:) = angleVec;
centroidMatrix(j,:) = centroidVec;

%pause(1/20);

end
stop(vid2);
delete(vid2);
```