BIOMECHANICS OF HEALTHY HUMAN'S GAIT

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Abstract: Most people are extremely skilled in many everyday movements like standing, walking, or climbing stairs. Unfortunately, modern living does not require enough movement to prevent several chronic diseases associated with low physical activity. Fortunately, many human movement professions like physical educators, coaches, athletic trainers, strength & conditioning coaches, personal trainers, and physical therapists help people reap the benefits of physical activity.

Kinesiology is the term referring to the whole scholarly area of human movement study, while biomechanics is the study of motion and its causes in living things. Biomechanics provides key information on the most effective and safest movement patterns, equipment, and relevant exercises to improve human movement. In a sense, kinesiology professionals solve human movement problems every day, and one of their most important tools is biomechanics. This work outlines the field of biomechanics, why biomechanics is such an important area and where biomechanics information can be found. The aim of this study was to present some possible quantitative and qualitative measurements of human's gait using simple Software Kinovea and Scilab and to determine kind of gait pattern for examined persons.

This paper describes gait as a one of human's motion pattern. It also details two "regions" of biomechanics analysis which are qualitative and quantitative analysis and their influence on human's everyday life.

Keywords: Biomechanical study, Quantitative, Qualitative, Human movement, Gait

1 Introduction

Biomechanics has been defined as the study of the movement of living things using the science of mechanics (H.Hatze, 1974). Mechanics is a branch of physics that is concerned with the description of motion and how forces create motion. Forces acting on living things can create motion, be a healthy stimulus for growth and development, or overload tissues, causing injury. Biomechanics provides conceptual and mathematical tools that are necessary for understanding how living things move and how kinesiology professionals might improve movement or make movement safer. Kinesiology is the academic area for the study of human movement (Corbin & Eckert, 1990). [7]

Biomechanics provides information for a variety of kinesiology professions to analyze human movement to improve effectiveness or decrease the risk of injury. How the movement is analyzed falls on a continuum between a qualitative analysis and a quantitative analysis. [7]

Quantitative analysis involves the measurement of biomechanical variables and usually requires a computer to do the voluminous numerical calculations performed. Even short movements will have thousands of samples of data to be collected, scaled, and numerically processed. In contrast, qualitative analysis has been defined as the "systematic observation and introspective judgment of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance" (Knudson & Morrison, 2002, p. 4). [7]

Analysis in both quantitative and qualitative contexts mean identification of the factors that affect human movement performance, which is then interpreted using other higher levels of thinking (synthesis, evaluation) in applying the information to the movement of interest. Solving problems in human movement involves high levels of critical thinking and an interdisciplinary approach, integrating the many kinesiology sciences. [7]

2 Theme development

2.1 Gait as a pattern of motion

The gait cycle is defined as the time interval between two successive occurrences of one of the repetitive events of walking. Although any event could be chosen to define the gait cycle, it is generally convenient to use the instant at which one foot contacts the ground ('initial contact'). If it is decided to start with initial contact of the right foot, then the cycle will continue until the right foot contacts the ground again. [4]

Two phases of gait can be distinguished: stance phase, which is also called the 'support phase' or 'contact phase' when the foot is on the ground; lasts from initial contact to toe off. It is subdivided into: loading response, mid-stance, terminal stance and pre-swing. The other one is swing phase, when the foot is moving forward through the air. The swing phase lasts from toe off to the next initial contact. It is subdivided into: initial swing, mid-swing and terminal swing. The representation of each phase of gait is presented below (Fig. 1). [4]

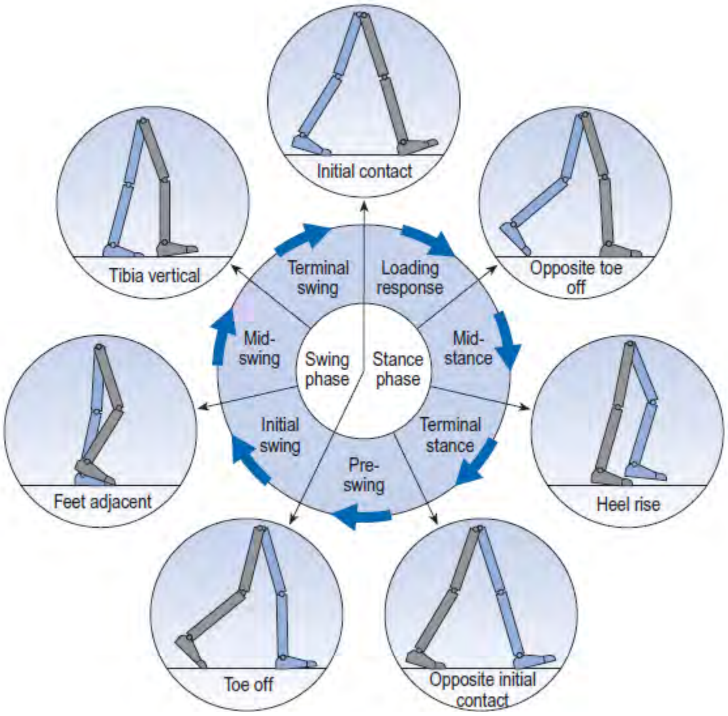


Fig. 1.: Positions of the legs during a single gait cycle by the right leg (gray) [4]

Double support phase is when one foot is forward, having just landed on the ground, and the other one is backward, being just about to leave the ground. In each gait cycle, there are thus two periods of double support and two periods of single support. The stance phase usually lasts about 60% of the cycle, the swing phase about 40% and each period of double support about 10%. The swing phase becomes proportionately longer and the stance phase as well as double support phases becomes shorter, as the speed increases. The final disappearance of the double support phase marks the transition from walking to running. Between successive steps in running there is a flight phase, also known as the 'float', 'double-float' or 'non-support' phase, when neither foot is on the ground. [4]

During gait, important movements occur in all three planes – sagittal, frontal and transverse. However, the largest movements occur in the sagittal plane. That is the reason that all this research has been carried out in a sagital plane. All of the planes are presented below in Fig. 2. [4]

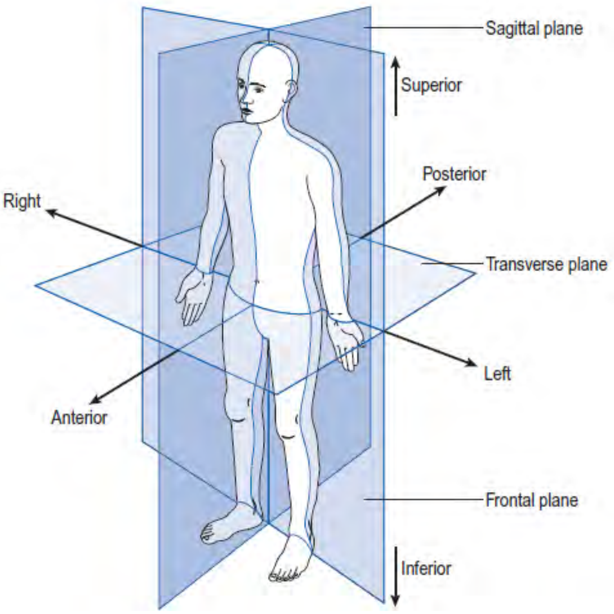


Fig. 2.: The anatomical position, with three reference planes and six fundamental directions [4]

2.2 Gait cycle

Each of the following sections consider some general remarks about the events surrounding a particular event in the gait cycle.

Initial contact - the beginning of the loading response, which is the first period of the stance phase. Initial contact is frequently called 'heelstrike', since in normal individuals there is often a distinct impact between the heel and the ground, known as the 'heelstrike transient'. Other names for this event are 'heel contact', 'footstrike' or 'foot contact'. The direction of the ground reaction force changes from generally upwards turning the heelstrike transient to upwards and backward in the loading response, immediately afterwards.

Loading responce - the double support period between initial contact and opposite toe off. During this period, the foot is lowered to the ground by plantarflexion of the ankle. The ground reaction force increases rapidly in magnitude, its direction being upwards and backwards. Loading response typically occupying the first 10–12% of the cycle.

Opposite toe off - the end of the double support period known as loading response and the beginning of midstance, the first period of single support. The forefoot, which was being lowered by plantarflexion of the ankle, contacts the ground at 'foot flat', also known as 'forefoot contact', which generally occurs around the time of opposite toe off. On the opposite (left) side, it marks the end of the stance chase and the beginning of the swing phase.

Mid-stance - the period of the gait cycle between opposite toe off and heel rise, although the term has been used in the past to describe an event of the gait cycle- the time at which the swing phase leg passes the stance phase leg, corresponding to the swing phase event of 'feet adjacent'.

Heel rise - marks the transition from midstance to terminal stance. It is the time, at which the heel begins to lift from the walking surface. Its timing varies considerably, both from one individual to another and with the speed of walking.

Opposite initial contact –as might be expected, opposite initial contact in symmetrical gait occurs at close to 50% of the cycle. It marks the end of the period of single support and the beginning of pre-swing, which is the second period of double support. At the time of opposite initial contact, also known as 'opposite foot contact', the hip begins to flex, the knee is already flexing and the ankle is plantarflexing. The period between heel rise and toe off (terminal stance followed by pre-swing) is sometimes called the 'terminal rocker'. This is appropriate, since the leg is now rotating forwards about the forefoot, rather than about the ankle joint.

Toe off generally occurs at about 60% percent of the gait cycle. It separates pre-swing from initial swing and is the point at which the stance phase ends and the swing chase begins. The name 'terminal contact' has been proposed for this event, since in pathological gait the toe may not be the last part of the foot to leave the ground.

Feet adjacent separates initial swing from mid-swing. It is the time when the swinging leg passes the stance phase leg and the two feet are side by side. The swing phase occupies about 40% of the gait cycle and the feet become adjacent around the center of this time. Alternative names for feet adjacent are 'foot clearance' and 'mid-swing'; the latter term is now applied to a period of the gait cycle, rather than to a particular event. Initial swing is also known as 'lift off '.

Tibia vertical - the division between the periods of mid-swing and terminal swing is marked by the tibia of the swinging leg becoming vertical. Terminal swing is also known as 'reach'.

Terminal foot contact - the gait cycle ends at the next initial contact of the same foot (in this case, the right foot). Because it is confusing to refer to the end of the cycle as 'initial contact', it is sometimes known as 'terminal foot contact'. [4]

2.3 Most important gait parameters

The cyclic nature of human gait is a very useful feature for reporting different parameters. There are literally hundreds of parameters that can be expressed in terms of the percent cycle. For the aim of this article it was chosen just a few examples to illustrate this point. There can be distinguished distance (spatial) and time (temporal) variables. Distance variables are: step length, stride length, width of walking base and foot angle (degree of toe out or angle of gait). Time variables are: step time, stride time, stance time, single limb time, double limb time, swing time, cadence and speed. [9]

Step length- distance between corresponding successive points of heel contact of the opposite feet. For right leg step length is equal with left leg (in a normal gait).

Stride Length- distance between successive points of heel contact of the same foot. Its is double the step length (in normal gait).

Walking Base- side-to-side distance between the line of the two feet. It is also known as 'stride width'.

Degree of toe out- it represents the angle of foot placement and may be found by measuring the angle formed by each foots line of progression and a line intersecting the center of the heel and the second toe. The angle for men is about 7°. The degree of toe out decreases as the speed of walking increases in normal men.

Step time- it is referred to the amount of time spent during single step. It is the time between heel strike of one leg and heel strike of the contra-lateral leg.

Stride time- it is referred to the amount of time it takes to complete one stride. Stride duration and gait cycle duration are the same.

Stance time- it is the amount of time that passes during the stance phase of one extremity in a gait cycle. It includes single support and double support.

Swing time- it is the amount of time that passes during the swing phase of one extremity in a gait cycle. If the stride time of the gait cycle is one second, the stance time is 0.6 second and swing time is 0.4 second.

Single limb time- it is the amount of time that passes during the period when only one extremity is on the supporting surface in a gait cycle.

Double limb time- it is the amount of time that a person spends with both feet on the ground during one gait cycle. The percentage of time spent in double support decreases as the speed of walking increases.

Cadence- number of steps per unit time. Normally it is 100 – 115 steps/min .

Speed (Velocity)- distance covered by the body in unit time. Usually measured in m/s. Instantaneous velocity varies during the gait cycle. Average velocity (m/min) = step length (m) x cadence (steps/min). Average walking speed = 80m/minute. [9]

2.4 Purposes of the study human's gait

From the clinical point of view, the importance of human gait analysis lies in the fact that gait disorders affect a high percentage of the world's population and are key problems in neurodegenerative diseases such as multiple sclerosis, amyotrophic lateral sclerosis or Parkinson's disease, as well as in many others such as myelopathies, spinal amyotrophy, cerebellar ataxia, brain tumors, cranioencephalic trauma, neuromuscular diseases (myopathies), cerebrovascular pathologies, certain types of dementia, heart disease or physiological ageing. Study of human gait characteristics may be useful for clinical applications and may benefit the various groups suffering from gait-related disorders. In the elderly, physical exercise has a major impact on osteoporosis, because it significantly helps to prevent falls, which are the biggest risk factor for this age group. Therefore, evaluation of gait quality may be valuable for early diagnosis of disease such as osteoporosis. Many neurodegenerative and age-related diseases such as Parkinson's are linked to other parameters which make it possible to diagnose and know the patient's evolution. New methods have great impact in various fields such as human recognition, sports, and especially in the clinical field, where objective gait analysis plays an important role in diagnosis, prevention and monitoring of neurological, cardiopathic and age-related disorders. [1]

2.5 Qualitative analysis

The purpose of a qualitative anatomical analysis is to determine the predominant muscular activity during specific phases of a performance and to identify instants when large stresses may occur due to large muscle forces or extremes in joint ranges of motion. [6] Qualitative analysis of gait (walking) also helps the therapist decide whether sufficient muscular strength and control have been regained in order to permit safe or cosmetically normal walking. [7] The results included measurements of gait in slow motion for 5 health persons and motion analysis in the ankle, knee, hip and tibia. Analysis was carried out only in sagital plane, because of using only one camera. The range of movement in these body parts are extension, flexion and neutral position.

2.6 Quantitative analysis

A quantitative gait analysis is generally considered to be any objective means that can be used to measure walking performance. The procedure can be as simple as measuring step length with a ruler or determining cadence with a stopwatch, or it can be as sophisticated as full-body motion capture with state-of-the-art instrumentation. Regardless of the methods, the measurements that are collected, are used to assess the quality of the gait and to characterize the motion. Gait analyses are typically performed before and after the intervention to determine efficacy of treatment. Treatment is considered beneficial if improvement in the gait pattern is observed, evident by a reduction in abnormal movements with an evolution toward patterns that are more like those of able-bodied individuals. [2] In this work there were made three parts connected with quantitative analysis of gait. First part was calibration of video of human's gait. This calibration was made in two ways: in Kinovea and Scilab Software to compare results from these two programs. Second part of this research was analyzing human's gait by its parameters like velocity and acceleration. The aim was to put values from Kinovea to Excel and based on it, to make some plots, which showed how velocity and acceleration are changing in the time of walking. Adding trendline made plots more clear. Third part of quantitative analysis was to find centers of mass of human body. It was conducted using a code in Scilab and allowed to determine a center of mass each segment of body and then of all the body. The results included plots which presents how the center of body is changing in each phase of walking.

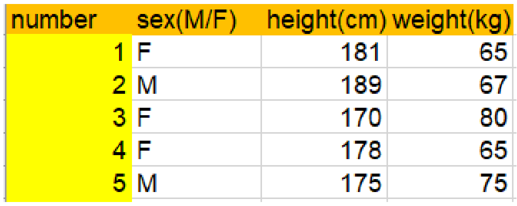
3 Systematic observation

Systematic observation means, that it is not possible get credible results, if many tries won't be conducted. It is important to make at least 3 trials to get credible results. Another thing which is essential in carrying out experiment is to plan the whole process of research. It is significant to determine place, right equipment (camera, tripod, bars, markers) and people who we will be 'investigating'. The research was conducted on 5 people (3 woman and 2 man), with no significant gait disorders. Another essential thing while carrying out the experiment is making sure that investigated people have proper clothes. It is really important to have shorts and t-shirt what enables to observe knee, shoulder, elbow, wrist and another important parts of the body. Investigated persons should also have proper shoes, for good ankle visibility.

4 Result

4.1 Qualitative analysis of human's gait

Results contain motion analysis of 5 investigated persons in the ankle, tibia, knee and hip for left and right leg carried out in sagital plane (Fig. 7, 8). The range of movement in these body parts are extension, flexion and neutral position. There is also presented personal data of each examined persons (Fig. 3). The analysis was conducted on the basic on slow motion videos of natural walking of 5 examined persons, which were recorded during working on this article. Range of movement for different parts of body were presented in Fig. 4 ,5, 6.



number	sex(M/F)	height(cm)	weight(kg)
1	F	181	65
2	M	189	67
3	F	170	80
4	F	178	65
5	M	175	75

Fig. 3.: Personal data for examined persons

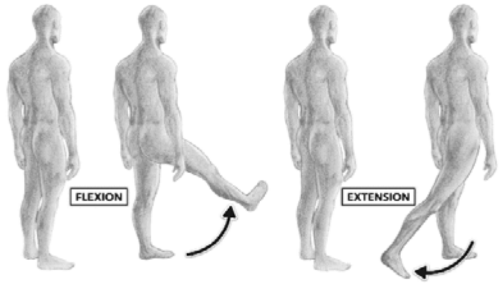


Fig. 4.: Flexion and extension at the hip [8]

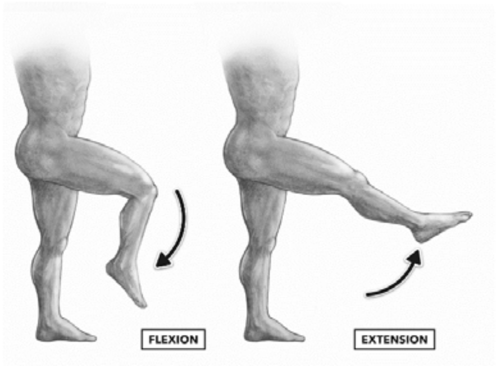


Fig. 5.: Flexion and extension at the knee [8]

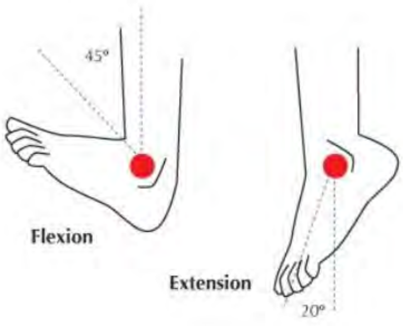


Fig. 6.: Flexion and extension at the ankle [8]

Left					Person 1	Person 2	Person 3	Person 4	Person 5
Sagital	Stance Phase	Loading response	Initial Contact	Ankle	extension	extension	extension	extension	extension
				Tibia	extension	extension	extension	extension	extension
				Knee	extension	flexion	extension	flexion	flexion
				Hip	flexion	flexion	flexion	flexion	flexion
		Mid-stance	opposite toe off	Ankle	extension	neutral	neutral	neutral	neutral
				Tibia	extension	neutral	neutral	extension	neutral
				Knee	extension	flexion	neutral	flexion	flexion
				Hip	flexion	flexion	neutral	flexion	flexion
		Terminal - stance	heel rise	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	extension	extension	flexion	extension	flexion
				Hip	extension	extension	extension	extension	extension
		Pre-swing	opposite initial contact	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	extension	flexion	flexion	extension	flexion
				Hip	extension	extension	extension	extension	extension
	Swing Phase	Initial swing	Toe off	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	flexion	flexion	flexion	flexion	flexion
				Hip	neutral	extension	extension	extension	extension
		Mid swing	feet adjacent	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	flexion	flexion	flexion	flexion	flexion
				Hip	flexion	flexion	flexion	flexion	flexion
		Terminal- swing	tibia vertical	Ankle	flexion	neutral	extension	neutral	extension
				Tibia	neutral	neutral	neutral	neutral	neutral
				Knee	flexion	flexion	flexion	flexion	flexion
				Hip	flexion	flexion	flexion	flexion	flexion

Fig. 7.: Results for 5 examined persons (left leg) in sagital plane- quantitative analysis of gait

Right									
Sagital	Stance Phase	Loading response	Initial Contact	Ankle	extension	extension	extension	extension	extension
				Tibia	extension	extension	extension	extension	extension
				Knee	extension	flexion	extension	flexion	flexion
				Hip	flexion	flexion	flexion	flexion	flexion
		Mid-stance	opposite toe off	Ankle	extension	neutral	neutral	neutral	neutral
				Tibia	extension	neutral	neutral	extension	neutral
				Knee	extension	flexion	neutral	flexion	flexion
				Hip	flexion	flexion	neutral	flexion	flexion
		Terminal - stance	heel rise	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	extension	extension	flexion	extension	flexion
				Hip	extension	extension	extension	extension	extension
		Pre-swing	opposite initial contact	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	extension	flexion	flexion	extension	flexion
				Hip	extension	extension	extension	extension	extension
	Swing Phase	Initial swing	Toe off	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	flexion	flexion	flexion	flexion	flexion
				Hip	neutral	extension	extension	extension	extension
		Mid swing	feet adjacent	Ankle	flexion	flexion	flexion	flexion	flexion
				Tibia	flexion	flexion	flexion	flexion	flexion
				Knee	flexion	flexion	flexion	flexion	flexion
				Hip	flexion	flexion	flexion	flexion	flexion
		Terminal- swing	tibia vertical	Ankle	flexion	neutral	extension	neutral	extension
				Tibia	neutral	neutral	neutral	neutral	neutral
				Knee	flexion	flexion	flexion	flexion	flexion
				Hip	flexion	flexion	flexion	flexion	flexion

Fig. 8.: Results for 5 examined persons (right leg) in sagital plane- quantitative analysis of gait

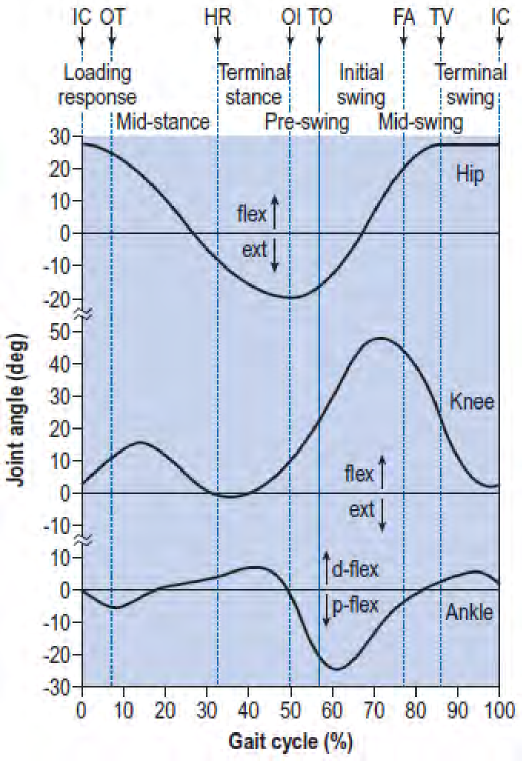


Fig. 9.: Sagital plane joint angles (degrees) during a single gait cycle of right hip (flexion positive), knee (flexion positive) and ankle (dorsiflexion positive) [4]

Most of the results for each phase are overlapping with those showed in the reference (Fig. 9). However, pattern of gait for each human is different, considering weight of body, individuals character of gait and some unknown disorders of gait, as well as for example spine diseases. This part was conducted to show how complicated are moves of human body and its individual parts during conducting one full cycle of gait.

4.2 Quantitative analysis- Calibration 2DDLT

The direct linear transformation (DLT) method has been one of most widely used camera digitalization and reconstruction algorithms. The relationship between the object space coordinates and the image plane coordinates are described by a set of cameras and markers placed in certain places. Strength of this method is much more accurate than Kinovea Software mathematical method, and it is not as complicated as 3DDLT one. Only one plane is needed (sagittal one in this case). Camera which was used for recordings was HTC U11 mobile phone camera. In slow motion it was able to record video in 120 fps in 1080p resolution. The experiment consisted of 3 parts.

1. Calibration is the setting or correcting of a measuring device or base level, usually by adjusting it to match or conform to a dependably known and unvarying measure. [10] To be confident in the results being measured there is an ongoing need to maintain the calibration of equipment throughout its lifetime for reliable, accurate and repeatable measurements. In this work it was necessary to make a calibration, because the experiment was carried out by using a camera. Calibration was done both in Kinovea Software and by using Scilab Software to compare both methods. It was necessary to create at least 4 points, which then were reference. Experiment was conducted by using 12 points, which gave more accurate measurement. These 12 points were used as reference ones. The goal was to determine the calibration coefficients and digital coordinates using Kinovea and Scilab Software. On the picture below (Fig. 10) it is presented how the experiment was runned. It consisted of 3 attempts.

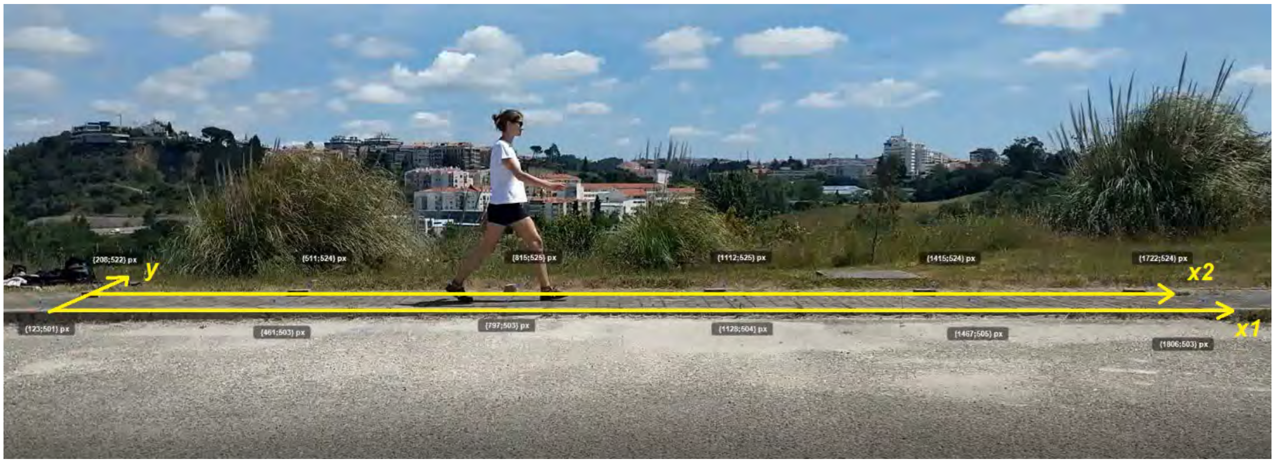
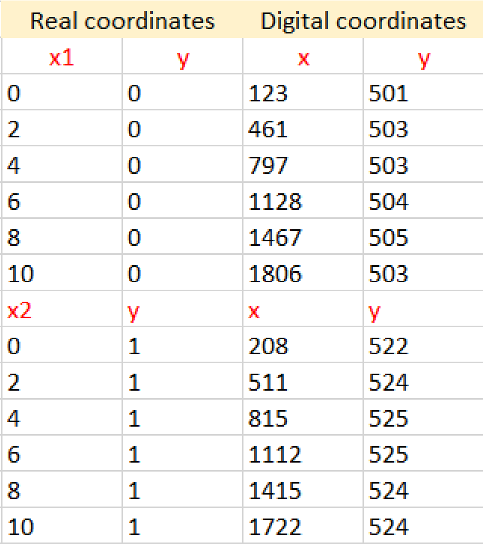


Fig. 10.: Digital coordinates pointed in Kinovea on our video of walking



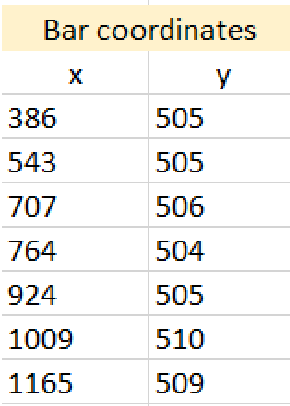
Real coordinates		Digital coordinates	
x1	y	x	y
0	0	123	501
2	0	461	503
4	0	797	503
6	0	1128	504
8	0	1467	505
10	0	1806	503
x2	y	x	y
0	1	208	522
2	1	511	524
4	1	815	525
6	1	1112	525
8	1	1415	524
10	1	1722	524

Fig. 11.: Real and digital coordinates of 12 reference points from Kinovea putted in Excel (first attempt)

2.Measuring the bars- Second part of this work was to measure lengths of bars. In this case there were used stones, on which were putted some well-visible tape. Configuration of bars was 2m- first bar, 1m- second bar, 1m- third bar. They were placed parallel to camera to avoid errors caused by angle between camera and object.

It was necessary to make calibrations of bars in Kinovea Software what we can see below in Fig. 12. Also it was important to put points of localization of bars (7 points) which then were used in Scilab Software (Fig. 13).

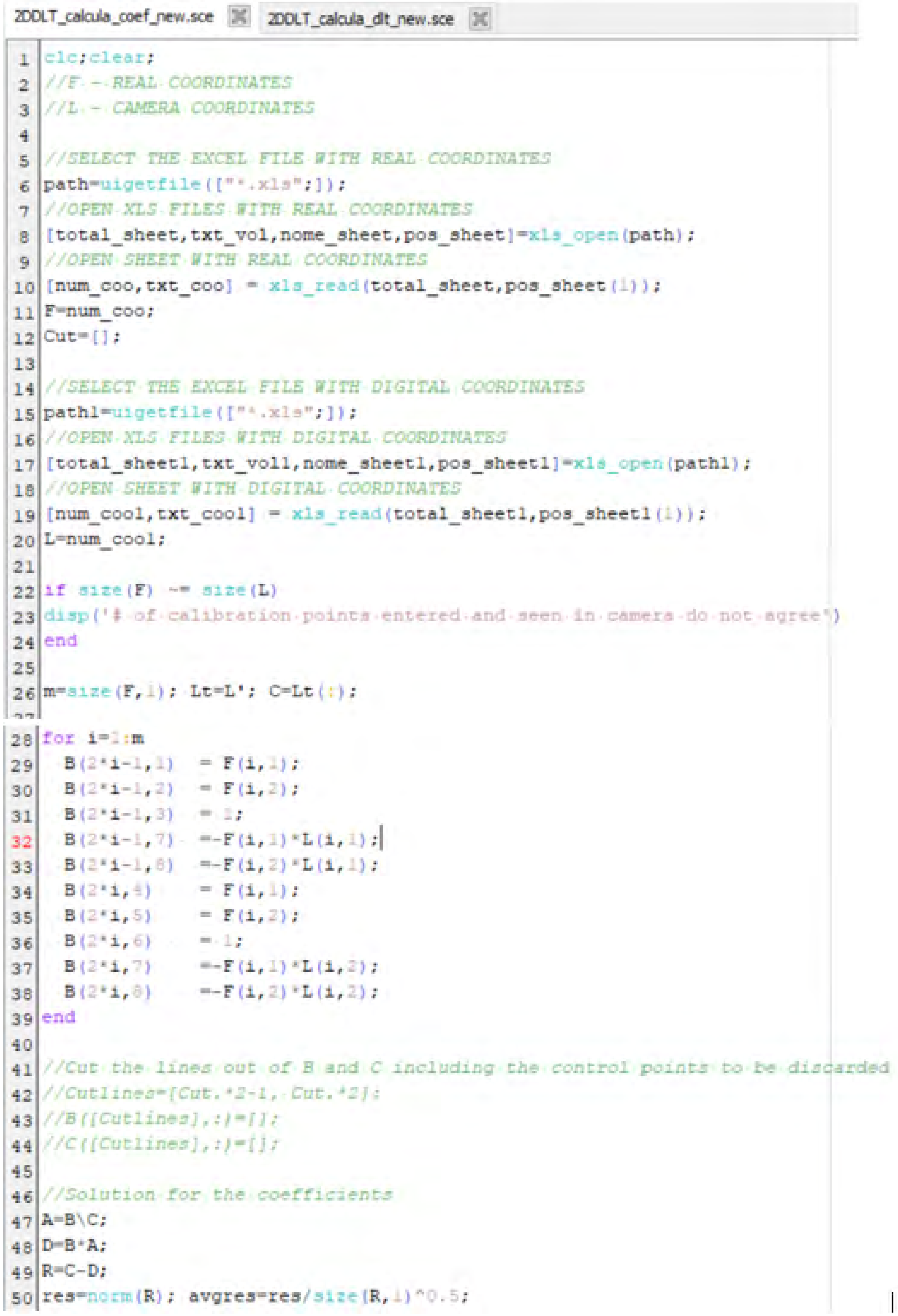
Fig. 12.: Calibration of bars in Kinovea (third attempt)



Bar coordinates	
x	y
386	505
543	505
707	506
764	504
924	505
1009	510
1165	509

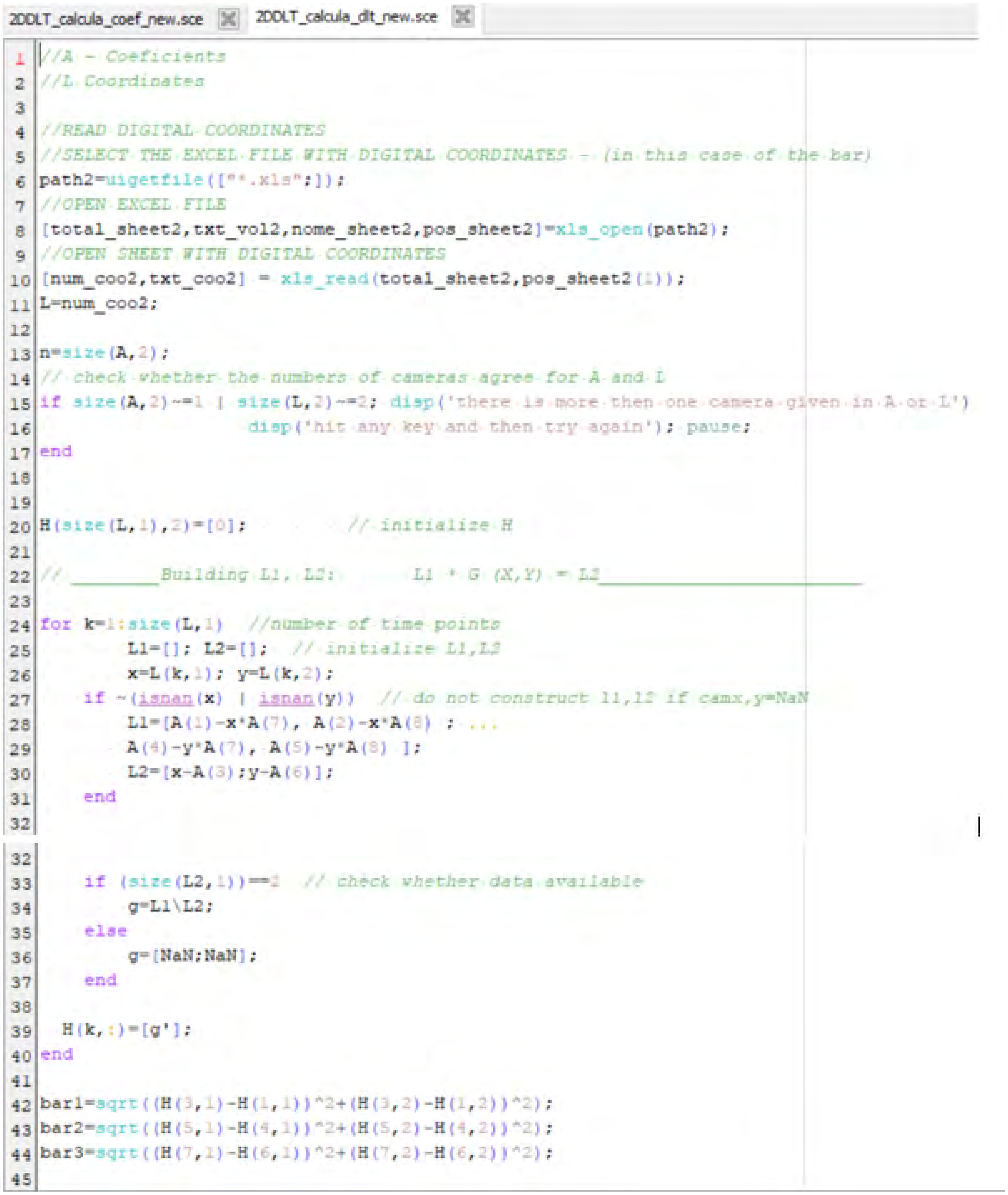
Fig. 13.: Localization of bars (7 points) from Kinovea (first attempt)

3. Authors of this article prepared 2 codes in Scilab Software presented in Fig. 14 and 15. First step in code 1 (Fig.14) was to open real and digital coordinates of reference points known from Kinovea. We obtained value of coefficient "A". Then by using code 2 (Fig. 15) and knowing value "A" it was necessary to open file with digital coordinates of bars. We obtained coefficient "H". Based on those codes, results of bar lengths were obtained (Fig. 16, 17, 18).



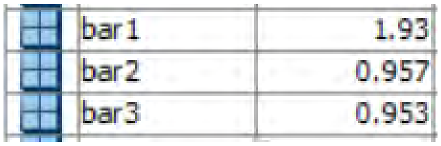
```
clc;clear;
//F - REAL COORDINATES
//L - CAMERA COORDINATES

//SELECT THE EXCEL FILE WITH REAL COORDINATES
path=uigetfile(["*.xls";]);
//OPEN XLS FILES WITH REAL COORDINATES
[total_sheet,txt_vol,nome_sheet,pos_sheet]=xls_open(path);
//OPEN SHEET WITH REAL COORDINATES
[num_coo,txt_coo] = xls_read(total_sheet,pos_sheet(1));
F=num_coo;
Cut=[];

//SELECT THE EXCEL FILE WITH DIGITAL COORDINATES
path1=uigetfile(["*.xls";]);
//OPEN XLS FILES WITH DIGITAL COORDINATES
[total_sheet1,txt_vol1,nome_sheet1,pos_sheet1]=xls_open(path1);
//OPEN SHEET WITH DIGITAL COORDINATES
[num_coo1,txt_coo1] = xls_read(total_sheet1,pos_sheet1(1));
L=num_coo1;

if size(F) ~= size(L)
disp('# of calibration points entered and seen in camera do not agree')
end

m=size(F,1); Lt=L'; C=Lt(:);

for i=1:m
  B(2*i-1,1)  = F(i,1);
  B(2*i-1,2)  = F(i,2);
  B(2*i-1,3)  = 1;
  B(2*i-1,7)  =-F(i,1)*L(i,1);
  B(2*i-1,8)  =-F(i,2)*L(i,1);
  B(2*i,4)    = F(i,1);
  B(2*i,5)    = F(i,2);
  B(2*i,6)    = 1;
  B(2*i,7)    =-F(i,1)*L(i,2);
  B(2*i,8)    =-F(i,2)*L(i,2);
end

//Cut the lines out of B and C including the control points to be discarded
//Cutlines=[Cut.*2-1, Cut.*2];
//B([Cutlines],:)=[];
//C([Cutlines],:)=[];

//Solution for the coefficients
A=B\C;
D=B*A;
R=C-D;
res=norm(R); avgres=res/size(R,1)^0.5;
```

Fig. 14.: Code 1 in Scilab Software



```
//A - Coeficients
//L Coordinates

//READ DIGITAL COORDINATES
//SELECT THE EXCEL FILE WITH DIGITAL COORDINATES - (in this case of the bar)
path2=uigetfile(["*.xls";]);
//OPEN EXCEL FILE
[total_sheet2,txt_vol2,nome_sheet2,pos_sheet2]=xls_open(path2);
//OPEN SHEET WITH DIGITAL COORDINATES
[num_coo2,txt_coo2] = xls_read(total_sheet2,pos_sheet2(1));
L=num_coo2;

n=size(A,2);
// check whether the numbers of cameras agree for A and L
if size(A,2)~=1 | size(L,2)~=2; disp('there is more then one camera given in A or L')
                    disp('hit any key and then try again'); pause;
end


H(size(L,1),2)=[0];             // initialize H

// ________Building L1, L2:       L1 * G (X,Y) = L2_________________________

for k=1:size(L,1)   //number of time points
        L1=[]; L2=[];   // initialize L1,L2
        x=L(k,1); y=L(k,2);
    if ~(isnan(x) | isnan(y))   // do not construct l1,l2 if camx,y=NaN
        L1=[A(1)-x*A(7), A(2)-x*A(8) ; ...
        A(4)-y*A(7), A(5)-y*A(8) ];
        L2=[x-A(3);y-A(6)];
    end


    if (size(L2,1))==2  // check whether data available
        g=L1\L2;
    else
        g=[NaN;NaN];
    end

  H(k,:)=[g'];
end

bar1=sqrt((H(3,1)-H(1,1))^2+(H(3,2)-H(1,2))^2);
bar2=sqrt((H(5,1)-H(4,1))^2+(H(5,2)-H(4,2))^2);
bar3=sqrt((H(7,1)-H(6,1))^2+(H(7,2)-H(6,2))^2);

```

Fig. 15.: Code 2 in Scilab Software

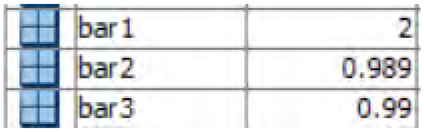


bar1	1.93
bar2	0.957
bar3	0.953

Fig. 16.: Bars lengths for the first attempt

bar1	2.07
bar2	1.03
bar3	1.02

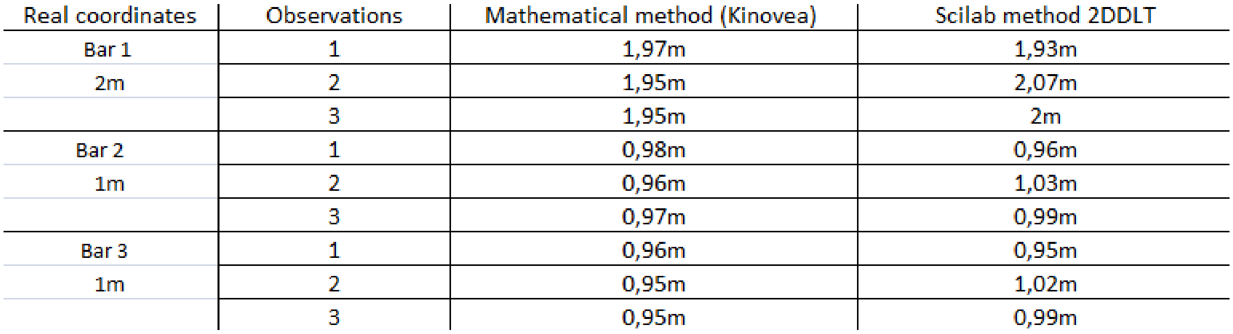
Fig. 17.: Bars lengths for the second attempt



bar1	2
bar2	0.989
bar3	0.99

Fig. 18.: Bars lengths for the third attempt

All the results are presented in Fig. 19. It contains the results both from Kinovea and Scilab Software. It is clearly visible that Scilab method is much more precise than Kinovea one. Results from both Kinovea and Scilab methods are similar or almost the same with the real values, so the calibration was made in a proper way.



Real coordinates	Observations	Mathematical method (Kinovea)	Scilab method 2DDLT
Bar 1	1	1,97m	1,93m
2m	2	1,95m	2,07m
	3	1,95m	2m
Bar 2	1	0,98m	0,96m
1m	2	0,96m	1,03m
	3	0,97m	0,99m
Bar 3	1	0,96m	0,95m
1m	2	0,95m	1,02m
	3	0,95m	0,99m

Fig. 19.: Results from calibration using Kinovea and Scilab Software

After performing calibration, it was possible to proceed to the next task.

4.3 Quantitative analysis- Obtaining and processing linear kinematic parameters

There are several methods to determine quantitatively the human motion. One of the methods that allow to quantify the human motion is through the kinematics methods (study the human motion without explain the forces action). It can be obtained through several tools, as for example, the cameras, but it is necessary to use mathematical methods to calculate the obtained data.

In this part first it was recorded video in slow motion of human's gait. Then using Kinovea, virtual marker on the ankle was putted and using this, the path of one step for right leg was obtained. Obtaining this, data from Kinovea was putted to Excel. Having this data, it was possible to calculate desired equations and plots. The goal was to determine **position, displacement, velocity and acceleration** of the step and using this, make several plots. It was possible by using first and second derivatives. The obtained signal was very rapid changing, and it demanded to put trendline to make it calmer. However, by using polynomial method in case of acceleration it still wasn't enough to clear the signal. The signal was changing very fast. Reasonable idea would be using in this case Butterworth filter as a code in Scilab, but we only be focused on Polynomial method of smoothing processing data. The results and some equations are presented below. The measurements were conducted only for person 1. The experiment is presented below (Fig. 20).

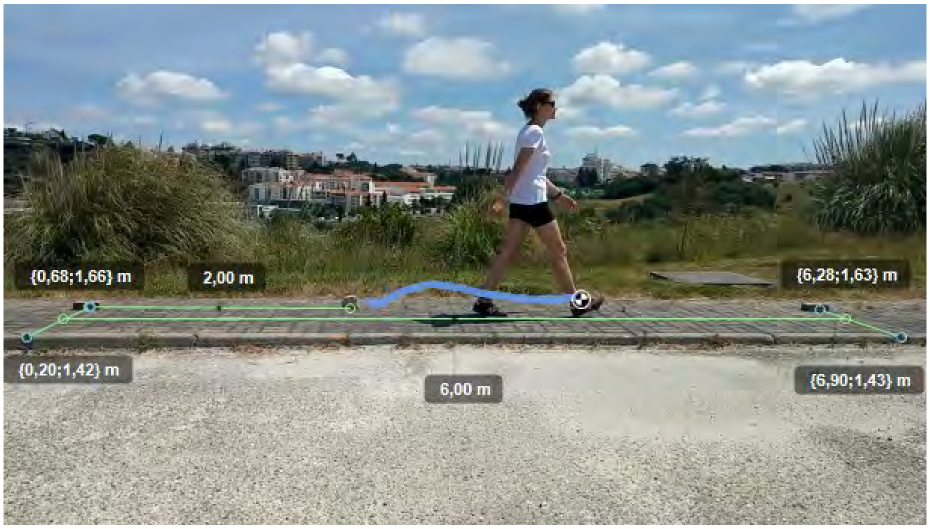
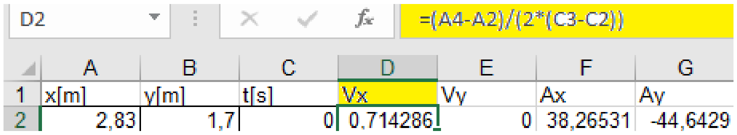


Fig. 20.: Obtaining and processing linear kinematic parameters by using Kinovea Software

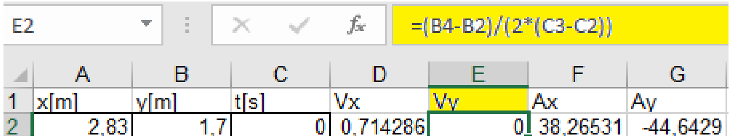


D2

=(A4-A2)/(2*(C3-C2))

	A	B	C	D	E	F	G
1	x[m]	y[m]	t[s]	Vx	Vy	Ax	Ay
2	2,83	1,7	0	0,714286	0	38,26531	-44,6429

Fig. 21.: Equation for obtaining velocity on position x (person 1)

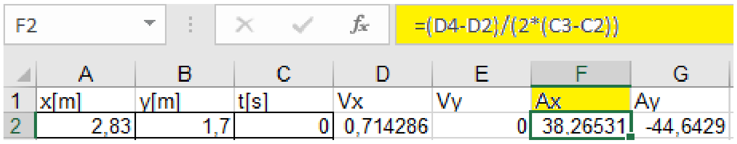


E2

=(B4-B2)/(2*(C3-C2))

	A	B	C	D	E	F	G
1	x[m]	y[m]	t[s]	Vx	Vy	Ax	Ay
2	2,83	1,7	0	0,714286	0	38,26531	-44,6429

Fig. 22.: Equation for obtaining velocity on position y (person 1)

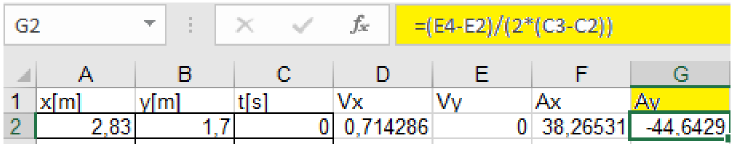


F2

=(D4-D2)/(2*(C3-C2))

	A	B	C	D	E	F	G
1	x[m]	y[m]	t[s]	Vx	Vy	Ax	Ay
2	2,83	1,7	0	0,714286	0	38,26531	-44,6429

Fig. 23.: Equation for obtaining acceleration on position x (person 1)



G2

=(E4-E2)/(2*(C3-C2))

	A	B	C	D	E	F	G
1	x[m]	y[m]	t[s]	Vx	Vy	Ax	Ay
2	2,83	1,7	0	0,714286	0	38,26531	-44,6429

Fig. 24.: Equation for obtaining acceleration on position y (person 1)

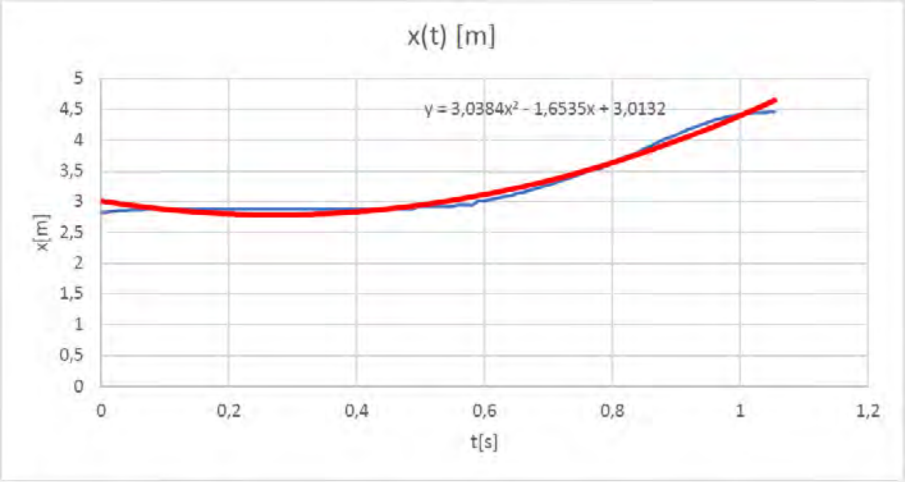


Fig. 25.: Linear position x(t) (person 1)

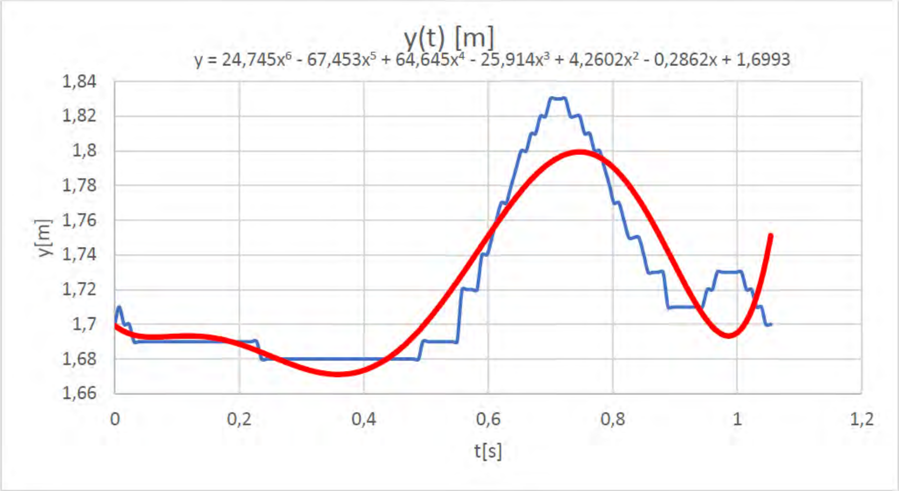


Fig. 26.: Linear position y(t) (person 1)

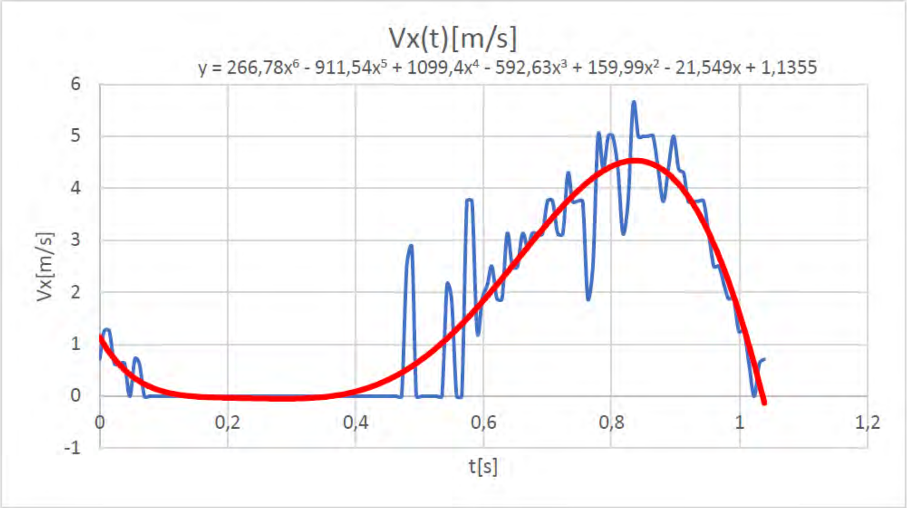


Fig. 27.: Linear velocity Vx(t) (person 1)

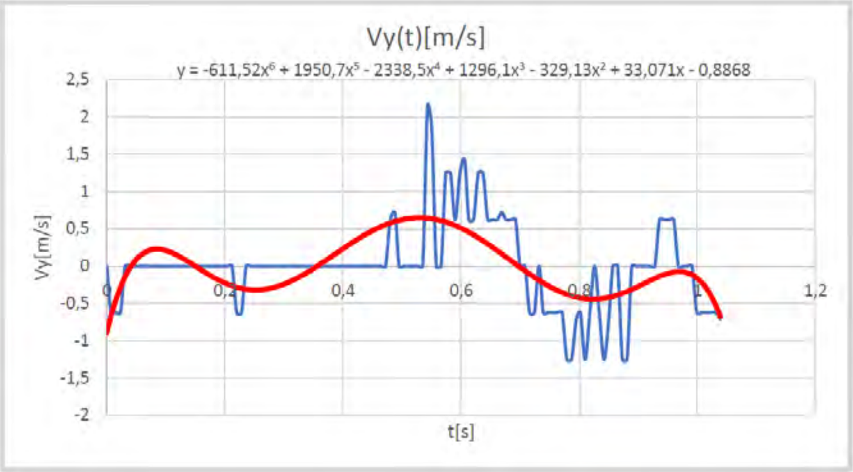


Fig. 28.: Linear velocity Vy(t) (person 1)

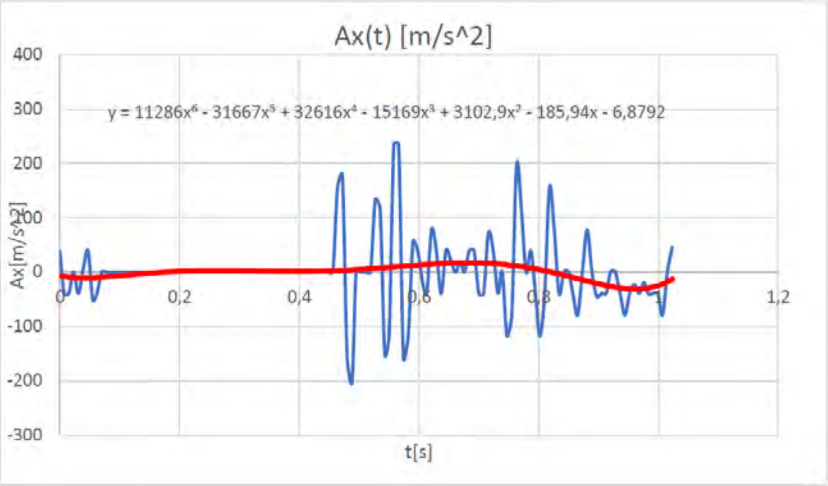


Fig. 29.: Linear acceleration Ax(t) (person 1)

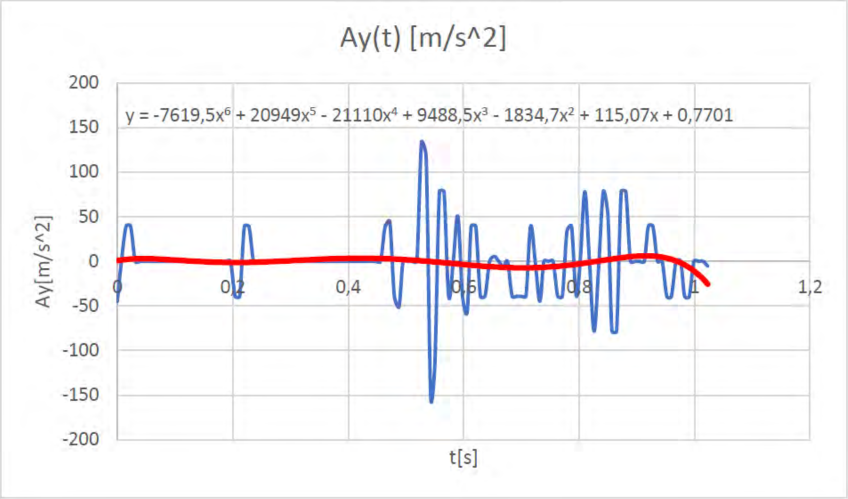


Fig. 30.: Linear acceleration Ay(t) (person 1)

Achieved plots gives view for kinematic movement parameters. On the beginning we obtained „x" and „y" coordinates of ankle. Video record framerate describes time in which displacement had place. By simple math we obtained velocity and acceleration of ankle. All data have been presented on plots, where „x" axis describes time, and „y": position, velocity and acceleration. Because of rough signal discretion, obtained velocity values are not changing smoothly (their values changes impulsively). Therefore, obtained acceleration values are not credible.

4.4 Quantitative analysis- Obtaining center of mass

The last stage of this work was to obtain information about mass centers of every examined person's body from record gait cycle. To this aim Kinovea and Scilab Software were used.

First part of the task was to develop code in Scilab. This code was able to use the Kinovea digital coordinates and on this basis calculate localization of certain body mass segment. The Scilab code for this purpose is presented below.

```
clc;clear;

//SELECT THE EXCEL FILE WITH DIGITAL COORDINATES
path1=uigetfile(["*.xls";]);
//OPEN XLS FILES WITH DIGITAL COORDINATES
[total_sheet1,txt_vol1,nome_sheet1,pos_sheet1]=xls_open(path1);
//OPEN SHEET WITH DIGITAL COORDINATES
[num_coo1,txt_coo1] = xls_read(total_sheet1,pos_sheet1(1));
L=num_coo1;

//1 right leg mid-foot
//2 right ankle
//3 right knee
//4 right hip
//5 right trunk
//6 right middle finger
//7 right wrist
//8 right elbow
//9 right arm
//11 the top of the head
//10 chin
//12 left mid-foot
//13 left ankle
//14 left knee
//15 left hip
//16 left middle finger
//17 left wrist
//18 left elbow
//19 left arm

RSr_X=L(1,1)
RSr_Y=L(1,2)
Rkostka_X=L(2,1)
Rkostka_Y=L(2,2)
Rkolano_X=L(3,1)
Rkolano_Y=L(3,2)
RHip_X=L(4,1)
RHip_Y=L(4,2)
//Trunk_X=L(5,1)
//Trunk_Y=L(5,2)
RPs_X=L(6,1)
RPs_Y=L(6,2)
RNadg_X=L(7,1)
RNadg_Y=L(7,2)
RLok_X=L(8,1)
RLok_Y=L(8,2)
```

```
RRamie_X=L(9,1)
RRamie_Y=L(9,2)
Broda_X=L(10,1)
Broda_Y=L(10,2)
CzubekG_X=L(11,1)
CzubekG_Y=L(11,2)
LSr_X=L(12,1)
LSr_Y=L(12,2)
Lkostka_X=L(13,1)
Lkostka_Y=L(13,2)
Lkolano_X=L(14,1)
Lkolano_Y=L(14,2)
LHip_X=L(15,1)
LHip_Y=L(15,2)
LPs_X=L(16,1)
LPs_Y=L(16,2)
LNadg_X=L(17,1)
LNadg_Y=L(17,2)
LLok_X=L(18,1)
LLok_Y=L(18,2)
LRamie_X=L(19,1)
LRamie_Y=L(19,2)

SEG_XFootR=L(2,1)-(L(2,1)-L(1,1))*0.50
SEG_YFootR=L(2,2)-(L(2,2)-L(1,2))*0.50

SEG_XLegR=L(3,1)-(L(3,1)-L(2,1))*0.433
SEG_YLegR=L(3,2)-(L(3,2)-L(2,2))*0.433

SEG_XThighR=L(4,1)-(L(4,1)-L(3,1))*0.433
SEG_YThighR=L(4,2)-(L(4,2)-L(3,2))*0.433

SEG_XForearmR=L(8,1)-(L(8,1)-L(7,1))*0.430
SEG_YForearmR=L(8,2)-(L(8,2)-L(7,2))*0.430

SEG_XHandR=L(7,1)-(L(7,1)-L(6,1))*0.506
SEG_YHandR=L(7,2)-(L(7,2)-L(6,2))*0.506

SEG_XArmR=L(9,1)-(L(9,1)-L(8,1))*0.436
SEG_YArmR=L(9,2)-(L(9,2)-L(8,2))*0.436

SEG_XTrunkSH=(L(9,1)+L(19,1))*0.5
SEG_YTrunkSH=(L(9,2)+L(19,2))*0.5
SEG_XTrunkHip=(L(4,1)+L(15,1))*0.5
SEG_YTrunkHip=(L(4,2)+L(15,2))*0.5
SEG_XTrunk=((SEG_XTrunkSH)+(SEG_XTrunkHip))*0.5
SEG_YTrunk=((SEG_YTrunkSH)+(SEG_YTrunkHip))*0.5

SEG_XHead=L(10,1)-(L(10,1)-L(11,1))*1
SEG_YHead=L(10,2)-(L(10,2)-L(11,2))*1

SEG_XFootL=L(13,1)-(L(13,1)-L(12,1))*0.50
SEG_YFootL=L(13,2)-(L(13,2)-L(12,2))*0.50

SEG_XLegL=L(14,1)-(L(14,1)-L(13,1))*0.433
SEG_YLegL=L(14,2)-(L(14,2)-L(13,2))*0.433

SEG_XThighL=L(15,1)-(L(15,1)-L(14,1))*0.433
SEG_YThighL=L(15,2)-(L(15,2)-L(14,2))*0.433

SEG_XHandL=L(17,1)-(L(17,1)-L(16,1))*0.506
SEG_YHandL=L(17,2)-(L(17,2)-L(16,2))*0.506
```

```
SEG_XForearmL=L(18,1)-(L(18,1)-L(17,1))*0.430
SEG_YForearmL=L(18,2)-(L(18,2)-L(17,2))*0.430

SEG_XArmL=L(19,1)-(L(19,1)-L(18,1))*0.436
SEG_YArmL=L(19,2)-(L(19,2)-L(18,2))*0.436

CM_XLegR=(SEG_XFootR*0.015+SEG_XLegR*0.047+SEG_XThighR*0.1)/(0.015+0.047+0.1)
CM_YLegR=(SEG_YFootR*0.015+SEG_YLegR*0.047+SEG_YThighR*0.1)/(0.015+0.047+0.1)

CM_XLegL=(SEG_XFootL*0.015+SEG_XLegL*0.047+SEG_XThighL*0.1)/(0.162)
CM_YLegL=(SEG_YFootL*0.015+SEG_YLegL*0.047+SEG_YThighL*0.1)/(0.162)

CM_XLegRL=((SEG_XFootR*0.015+SEG_XLegR*0.047+SEG_XThighR*0.1)+(SEG_XFootL*0.015+SEG_XLegL*0.047+SEG_XThighL*0.1))/(2*(0.015+0.047+0.1))
CM_YLegRL=((SEG_YFootR*0.015+SEG_YLegR*0.047+SEG_YThighR*0.1)+(SEG_YFootL*0.015+SEG_YLegL*0.047+SEG_YThighL*0.1))/(2*(0.015+0.047+0.1))

CM_XHandR=(SEG_XHandR*0.006+SEG_XArmR*0.028+SEG_XForearmR*0.016)/(0.006+0.028+0.016)
CM_YHandR=((SEG_YHandR*0.006)+(SEG_YArmR*0.028)+(SEG_YForearmR*0.016))/(0.006+0.028+0.016)

CM_XHandL=((SEG_XHandL*0.006)+(SEG_XArmL*0.028)+(SEG_XForearmL*0.016))/(0.006+0.028+0.016)
CM_YHandL=((SEG_YHandL*0.006)+(SEG_YArmL*0.028)+(SEG_YForearmL*0.016))/(0.006+0.028+0.016)

CM_XHandRL=((SEG_XHandR*0.006+SEG_XArmR*0.028+SEG_XForearmR*0.016)+(SEG_XHandL*0.006)+(SEG_XArmL*0.028)+(SEG_XForearmL*0.016))/(2*(0.006+0.028+0.016))
CM_YHandRL=((SEG_YHandR*0.006)+(SEG_YArmR*0.028)+(SEG_YForearmR*0.016)+(SEG_YHandL*0.006)+(SEG_YArmL*0.028)+(SEG_YForearmL*0.016))/(2*(0.006+0.028+0.016))

CM_UpperBodyX=((SEG_XHead*0.081)+(SEG_XTrunk*0.497)+(SEG_XHandR*0.006)+(SEG_XArmR*0.028)+(SEG_XForearmR*0.016)+(SEG_XHandL*0.006)+(SEG_XArmL*0.028)+(SEG_XForearmL*0.016))/(0.081+0.497+0.006+0.028+0.016+0.006+0.028+0.016)
CM_UpperBodyY=((SEG_YHead*0.081)+(SEG_YTrunk*0.497)+(SEG_YHandR*0.006)+(SEG_YArmR*0.028)+(SEG_YForearmR*0.016)+(SEG_YHandL*0.006)+(SEG_YArmL*0.028)+(SEG_YForearmL*0.016))/(0.081+0.497+0.006+0.028+0.016+0.006+0.028+0.016)

CM_AllBodyX=((SEG_XFootR*0.015)+(SEG_XLegR*0.047)+(SEG_XThighR*0.1)+(SEG_XFootL*0.015)+(SEG_XLegL*0.047)+(SEG_XThighL*0.1)+(SEG_XHead*0.081)+(SEG_XTrunk*0.497)+(SEG_XHandR*0.006)+(SEG_XArmR*0.028)+(SEG_XForearmR*0.016)+(SEG_XHandL*0.006)+(SEG_XArmL*0.028)+(SEG_XForearmL*0.016))/(0.015+0.047+0.1+0.015+0.047+0.1+0.081+0.497+0.006+0.028+0.016+0.006+0.028+0.016)

CM_AllBodyY=((SEG_YFootR*0.015)+(SEG_YLegR*0.047)+(SEG_YThighR*0.1)+(SEG_YFootL*0.015)+(SEG_YLegL*0.047)+(SEG_YThighL*0.1)+(SEG_YHead*0.081)+(SEG_YTrunk*0.497)+(SEG_YHandR*0.006)+(SEG_YArmR*0.028)+(SEG_YForearmR*0.016)+(SEG_YHandL*0.006)+(SEG_YArmL*0.028)+(SEG_YForearmL*0.016))/(0.015+0.047+0.1+0.015+0.047+0.1+0.081+0.497+0.006+0.028+0.016+0.006+0.028+0.016)

//Right Leg
plot([RSr_X Rkostka_X],[RSr_Y Rkostka_Y])
plot([Rkostka_X Rkolano_X],[Rkostka_Y Rkolano_Y])
plot([Rkolano_X RHip_X],[Rkolano_Y RHip_Y])
plot(SEG_XFootR,SEG_YFootR,'ro')
plot(SEG_XLegR,SEG_YLegR,'ro')
plot(SEG_XThighR,SEG_YThighR,'ro')
//Left Leg
plot([LSr_X Lkostka_X],[LSr_Y Lkostka_Y])
plot([Lkostka_X Lkolano_X],[Lkostka_Y Lkolano_Y])
plot([Lkolano_X LHip_X],[Lkolano_Y LHip_Y])
plot(SEG_XFootL,SEG_YFootL,'ro')
plot(SEG_XLegL,SEG_YLegL,'ro')
plot(SEG_XThighL,SEG_YThighL,'ro')
//Right hand
plot([RPs_X RNadg_X],[RPs_Y RNadg_Y])
```

```
plot([RNadg_X RLok_X],[RNadg_Y RLok_Y])
plot([RLok_X RRamie_X],[RLok_Y RRamie_Y])
plot(SEG_XHandR,SEG_YHandR, 'ro')
plot(SEG_XForearmR,SEG_YForearmR, 'ro')
plot(SEG_XArmR,SEG_YArmR, 'ro')
//Left hand
plot([LPs_X LNadg_X],[LPs_Y LNadg_Y])
plot([LNadg_X LLok_X],[LNadg_Y LLok_Y])
plot([LLok_X LRamie_X],[LLok_Y LRamie_Y])
plot(SEG_XHandL,SEG_YHandL, 'ro')
plot(SEG_XForearmL,SEG_YForearmL, 'ro')
plot(SEG_XArmL,SEG_YArmL, 'ro')
//Trunk
plot([RRamie_X LHip_X],[RRamie_Y LHip_Y])
plot([LRamie_X RHip_X],[LRamie_Y RHip_Y])
plot(SEG_XTrunk,SEG_YTrunk, 'ro')
//Head
plot([Broda_X CzubekG_X],[Broda_Y CzubekG_Y])
plot(SEG_XHead,SEG_YHead, 'ro')

plot(CM_XLegR,CM_YLegR, 'go')
plot(CM_XLegL,CM_YLegL, 'go')
plot(CM_XLegRL,CM_YLegRL, 'go')

plot(CM_XHandR,CM_YHandR, 'go')
plot(CM_XHandL,CM_YHandL, 'go')
plot(CM_XHandRL,CM_YHandRL, 'go')
 plot(CM_AllBodyX,CM_AllBodyY, 'ko')
```

Next stage was to make digitalization of every phase (IC, OT, HS, OIC, TO, FA, TV). For every phase there were putted 19 points on body, every time selecting them in Kinovea in the same order. Having knowledge about distal and proximal points it was possible to obtain localization of center of mass of specific part of body.

Location in X:

$$Seg\_x=seg\_proximal-(seg\_proximal-seg\_distal)*CM\_seg \quad (1)$$

Location in Y:

$$Seg\_y=seg\_proximal-(seg\_proximal-seg\_distal)*CM\_seg \quad (2)$$

Values CM_seg we took from table (Fig.31).

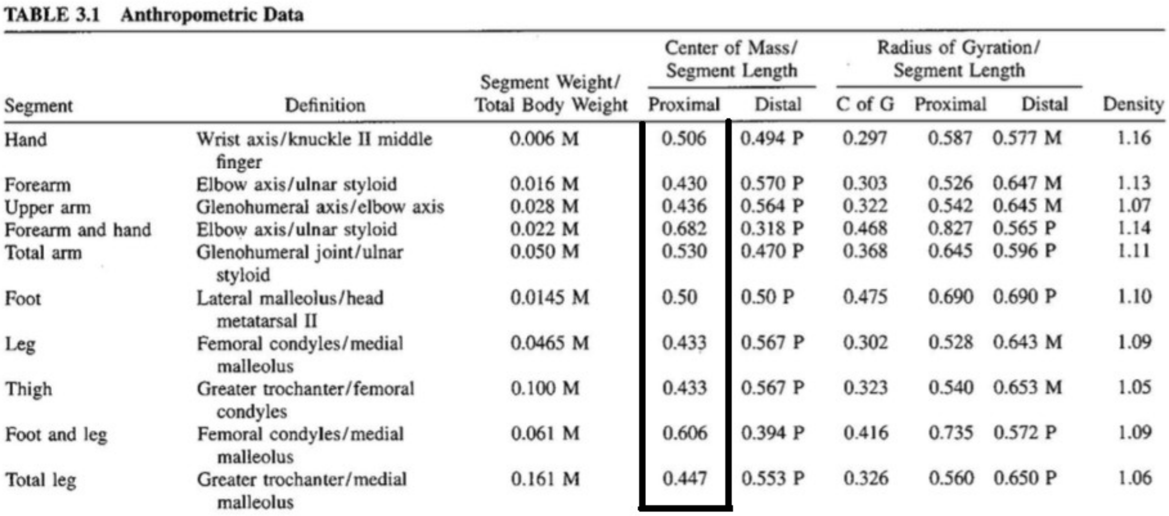


TABLE 3.1 Anthropometric Data

			Center of Mass/ Segment Length		Radius of Gyration/ Segment Length			
Segment	Definition	Segment Weight/ Total Body Weight	Proximal	Distal	C of G	Proximal	Distal	Density
Hand	Wrist axis/knuckle II middle finger	0.006 M	0.506	0.494 P	0.297	0.587	0.577 M	1.16
Forearm	Elbow axis/ulnar styloid	0.016 M	0.430	0.570 P	0.303	0.526	0.647 M	1.13
Upper arm	Glenohumeral axis/elbow axis	0.028 M	0.436	0.564 P	0.322	0.542	0.645 M	1.07
Forearm and hand	Elbow axis/ulnar styloid	0.022 M	0.682	0.318 P	0.468	0.827	0.565 P	1.14
Total arm	Glenohumeral joint/ulnar styloid	0.050 M	0.530	0.470 P	0.368	0.645	0.596 P	1.11
Foot	Lateral malleolus/head metatarsal II	0.0145 M	0.50	0.50 P	0.475	0.690	0.690 P	1.10
Leg	Femoral condyles/medial malleolus	0.0465 M	0.433	0.567 P	0.302	0.528	0.643 M	1.09
Thigh	Greater trochanter/femoral condyles	0.100 M	0.433	0.567 P	0.323	0.540	0.653 M	1.05
Foot and leg	Femoral condyles/medial malleolus	0.061 M	0.606	0.394 P	0.416	0.735	0.572 P	1.09
Total leg	Greater trochanter/medial malleolus	0.161 M	0.447	0.553 P	0.326	0.560	0.650 P	1.06

Fig. 31.: Table with anthropometric data (marked black is our CM_seg coefficient) [5]

Knowing Seg_x and Seg_y we can apply values, which corresponds to weight of certain parts of body:

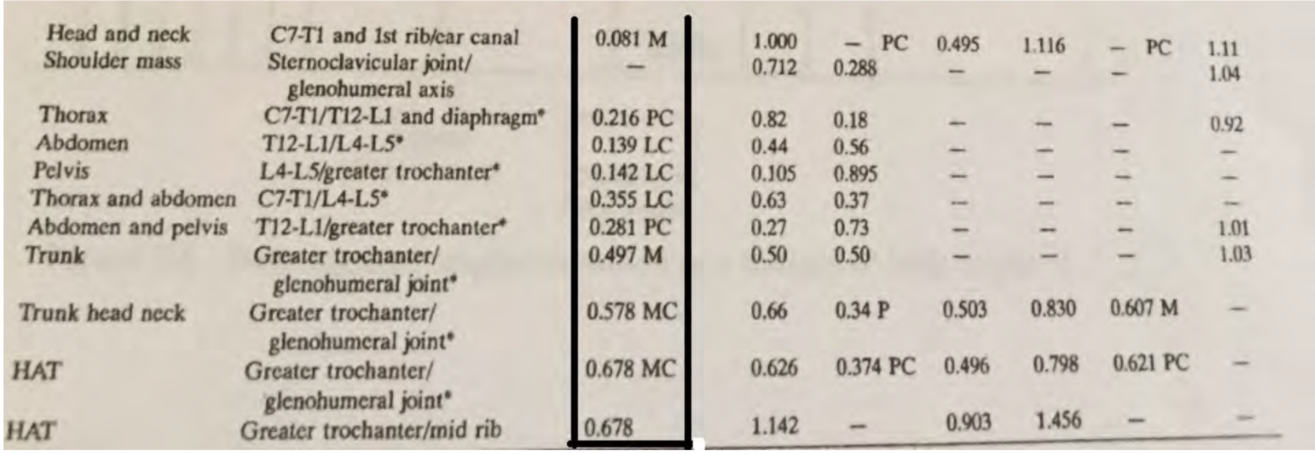
CM_X:

$$CM\_x=SUM(seg\_x*mass\_seg)/SUM(mass) \tag{3}$$

CM_Y:

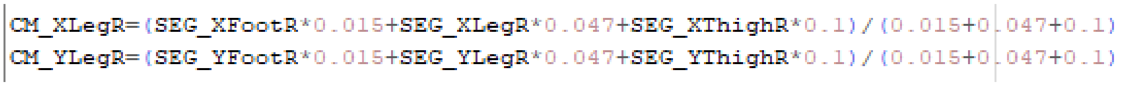
$$CM\_y=SUM(seg\_y*mass\_seg)/SUM(mass) \tag{4}$$

Values mass_seg were taken from Fig. 32.



Head and neck	C7-T1 and 1st rib/ear canal	0.081 M	1.000	— PC	0.495	1.116	— PC	1.11
Shoulder mass	Sternoclavicular joint/ glenohumeral axis	—	0.712	0.288	—	—	—	1.04
Thorax	C7-T1/T12-L1 and diaphragm*	0.216 PC	0.82	0.18	—	—	—	0.92
Abdomen	T12-L1/L4-L5*	0.139 LC	0.44	0.56	—	—	—	—
Pelvis	L4-L5/greater trochanter*	0.142 LC	0.105	0.895	—	—	—	—
Thorax and abdomen	C7-T1/L4-L5*	0.355 LC	0.63	0.37	—	—	—	—
Abdomen and pelvis	T12-L1/greater trochanter*	0.281 PC	0.27	0.73	—	—	—	1.01
Trunk	Greater trochanter/ glenohumeral joint*	0.497 M	0.50	0.50	—	—	—	1.03
Trunk head neck	Greater trochanter/ glenohumeral joint*	0.578 MC	0.66	0.34 P	0.503	0.830	0.607 M	—
HAT	Greater trochanter/ glenohumeral joint*	0.678 MC	0.626	0.374 PC	0.496	0.798	0.621 PC	—
HAT	Greater trochanter/mid rib	0.678	1.142	—	0.903	1.456	—	—

Fig. 32.: Table with mass of each body segment [5]



```
CM_XLegR=(SEG_XFootR*0.015+SEG_XLegR*0.047+SEG_XThighR*0.1)/(0.015+0.047+0.1)
CM_YLegR=(SEG_YFootR*0.015+SEG_YLegR*0.047+SEG_YThighR*0.1)/(0.015+0.047+0.1)
```

Fig. 33.: Part of code calculating centre of mass for right leg

When all data was collected, it was possible to make a plot, which shows how centers of masses of every body segment looks in every phase. Results are presented below.

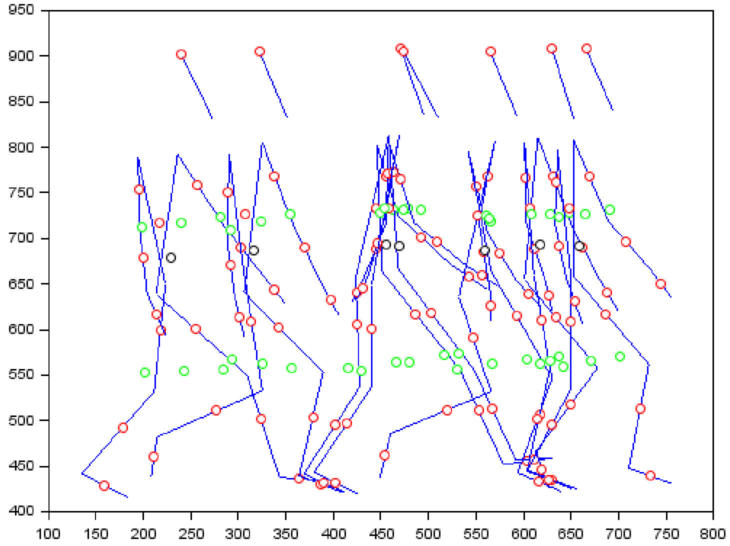


Fig. 34.: Result plot of program for every phase (from left IC, OT, HS, OIC, TO, FA, TV) for man of height 175cm and weight 75kg. Circle green signs mass center for upper and down body part, and black circle is all body mass center

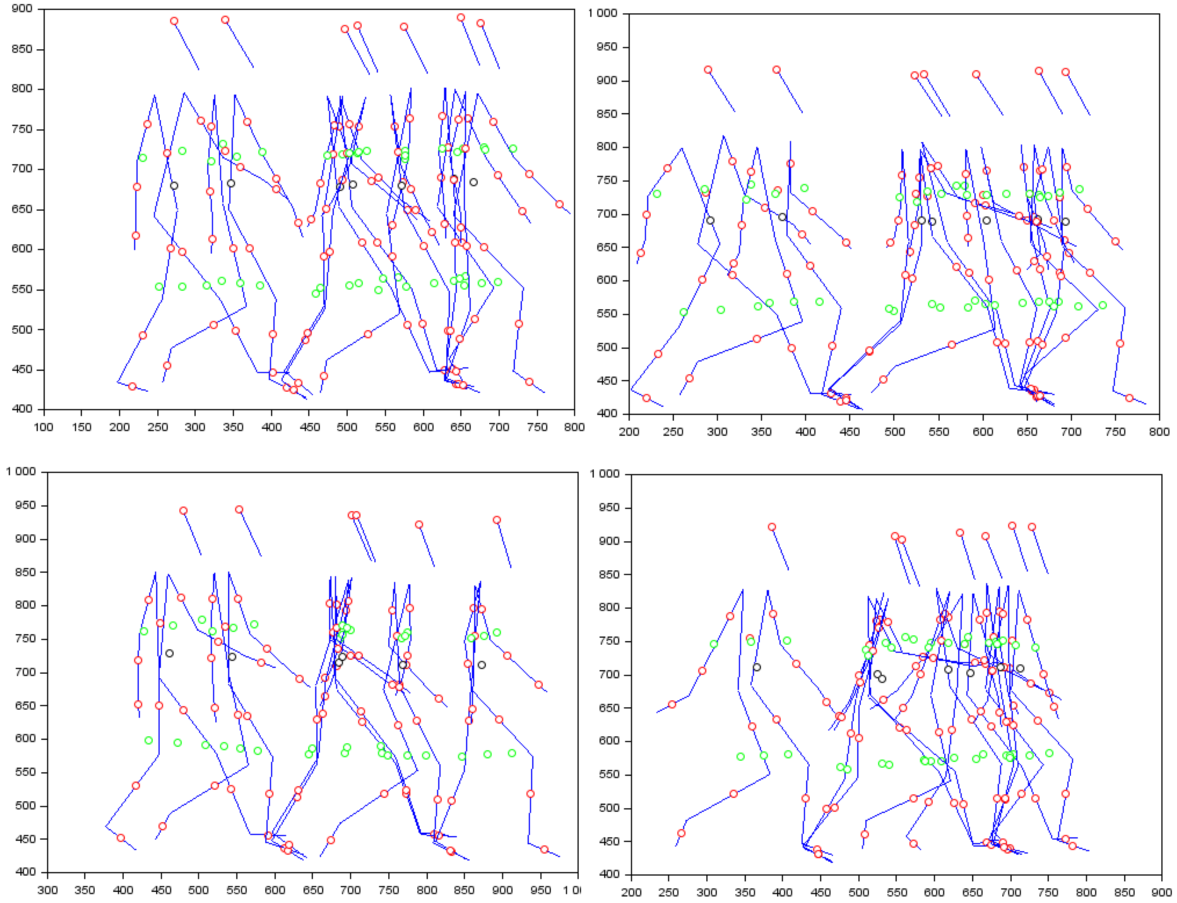


Fig. 35.: Comparison plots for rest of examned persons

Every person has point of mass center in a different place. Every of us has different body weight, anatomy, natural gait speed, and because of this every plot is different from another. To compare our results we put below the representation of center mass point while walking (Fig. 36).

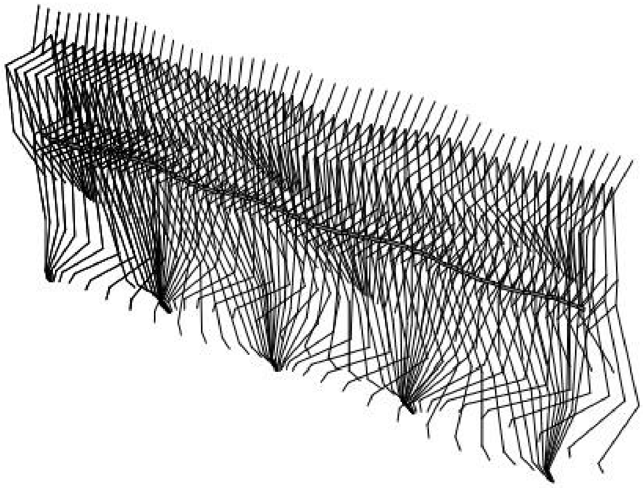


Fig. 36.: Model of subject during natural walking with drawn calculated trajectory of body center of mass [3]

5 Conclusions

Normal Gait is series of rhythmical , alternating movements of the trunk & limbs which result in the forward progression of the center of gravity and the body. Biomechanics of movement can be classified into two main areas: the improvement of performance and the reduction or treatment of injury. [7] Biomechanical research is a powerful ally in the sports medicine quest to prevent and treat injury. Biomechanical studies help prevent injuries by providing information on the mechanical properties of tissues, mechanical loadings during movement, and preventative or rehabilitative therapies. Biomechanical studies provide important data to confirm potential injury mechanisms hypothesized by sports medicine physicians. [7] People need help in improving human movement and this help requires knowledge of "why" and "how" the human body moves. Since biomechanics gives the kinesiology professional much of the knowledge and many of the skills necessary to answer these "what works?" and "why?" questions, biomechanics is an important science for solving human movement problems. [7]

The advantages of numerical measurements of quantitative over those of qualitative analysis are greater accuracy, consistency, and precision. Most quantitative biomechanical analysis is performed in research settings; however, more and more devices are commercially available that inexpensively measure some biomechanical variables (e.g., radar, timing lights, timing mats, quantitative videography systems). Unfortunately, the greater accuracy of quantitative measures comes at the cost of technical skills, calibration, computational and processing time, as well as dangers of increasing errors with the additional computations involved. Even with very fast modern computers, quantitative biomechanics is a labor-intensive task requiring considerable graduate training and experience. For these reasons and others, qualitative analysis of human movement remains the main approach kinesiology professionals use in solving most human movement problems. [7]

Qualitative and quantitative analysis of human gait makes possible to convert real body movement into digital path, what creates much more possibilities of analysis. Two methods which have been used in this article: Kinovea and 2DDLT are great tools for visualization of human gait movement. Comprising these two approaches, Kinovea is easier and fastest way to get the results. Accuracy of results mostly depends on camera resolution and precision in obtaining points of body parts.

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