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LOWER LIMB MATHEMATICAL MODELING WITH INERTIAL MOTION CAPTURE DURING NORMAL WALKING

Gennady Aryassov[1], Artem Kuznetcov[2], Victor Musalimov[2], Sergei Zhigailov[1(*)]

[1]Tallinn University of Technology (IDMEC), Tallinn, Estonia

[2]Department of Mechatronics, Saint-Petersburg National Research University of Information Technology, Mechanics and Optics

[(*)]*Email:* sergsil@gmail.com

ABSTRACT

This work is about methods and practices for measurement and analysis of human locomotion apparatus. Main attention is given for lower limbs. The research was focused on gait parameters estimation during test walking. Practical experience of Turner Research and Development Child Orthopedic Institute (Saint-Petersburg, Russian Federation) specialists was used in creation of experiments. They are experienced in questions of soft rehabilitation and surgery of the locomotion apparatus (LA). Experiments for human motion tracking were done for understanding of inertial measurement features. Analytical model of human leg was created and described in this work. Modelling analysis results were checked in practice.

Keywords: biomechanics, lower limb mathematical modelling, inertial motion capture, locomotion apparatus

INTRODUCTION

Authors analyzed related models of the human locomotion. Main issue of these systems is invariance estimation of human motion activity. Rehabilitation and estimation of functional motion parameters problems are high priority theme of scientific research. There is necessity of use of combined sensor types organization (such as sensors of acceleration and temperature) which is pointed out by several authors (Brusey, 2009). By using this type of organization it is possible to analyze interaction between different types of human systems, for example, bones and nervous system.

Attention is concentrated on development of low-cost motion estimation systems. This is important for increase of quantity of humans who can take high-qualificated medical service. The problem is a change of the methodological basis of medicine, where the main goal is not a treatment of occurred illnesses or a warning of the possible complications, but the prediction of disease based on the modeling of individual anthropometric data.

The prediction is particularly important in case of children's rehabilitation pathologies of locomotion apparatus due to their continuous development and growth (for example, a work in progress in the applicant company jointly with the Turner Research and Development Child Orthopedic Institute). Thus, the development of the proposed system is very popular and is at the level of world developments. The creation of this system is necessary to improve workplace of orthopedist and make it possible to analyze most common nosologic forms of disorders and injuries of LA, as well as disorders of blood circulation and innervation typical for the pathologies.

LA stands for 75% of body's mass and functions as support, helps in movement and inner organs protection. Musculoskeletal system illnesses in structure of primary disablement due to class of illness are 9,3% among adults and 5,7% among children in Russia(data by FGU GB MSE for 2011). According to that statistics quality improvement in medical care during LA illnesses and disorders becomes a priority task.

Pathological conditions can cause LA static and dynamical functional disorders. That's why system has to depict static interaction and dynamical load of support and movement organs. It will depict LA as the model, which main goal will be to graphically show anthropometric data, used in clinical biomechanics. Another important element is recreation of the individual model of patient's LA based on anthropometric data, gained by standard methods.

The use of interactive model of the individual patient`s locomotion apparatus with visualization of blood, supply, innervation and topography will improve the understanding of the lesion occurring in the process, the quality of care, and can also be used in the training of doctors orthopedic trauma as a visual aid.

TASK DESCRIPTION

It's necessary to analyze the parameters of the human movement for assessing the state of the lower human limbs. Walking is easy to simulate in the laboratory. For this a person needs to walk in a straight line in the room. Performing the task musculoskeletal system will perform a set of movements familiar to him. Next, we must measure motion parameters of human body parts.

SELECTION OF SENSORS

Research purpose has following requirements:

1. Easy to install on the human body;
2. The ability to control the movement of different body points.

It is important that the data is correct. This means that separate measurements of human motion with the same experimental conditions should be equal. To test this, we spend a few repeats of the gait parameters measurement and compare the data.

We selected wireless measurement system with accelerometers as the measuring modules (SmartSport). They can be easily placed in a desired point of the body due to the absence of wires and small size. The modules transfer data on the values of the three projections of the acceleration to the computer using Bluetooth.

Modules are installed on the human body using the patch with Curofix. It is specifically designed for use on the human body. The patch allows to tightly hold modules, eliminating the movement and rotation of it on the surface. Light weight of the module (about 12 grams) don't affects on the movement of patient.

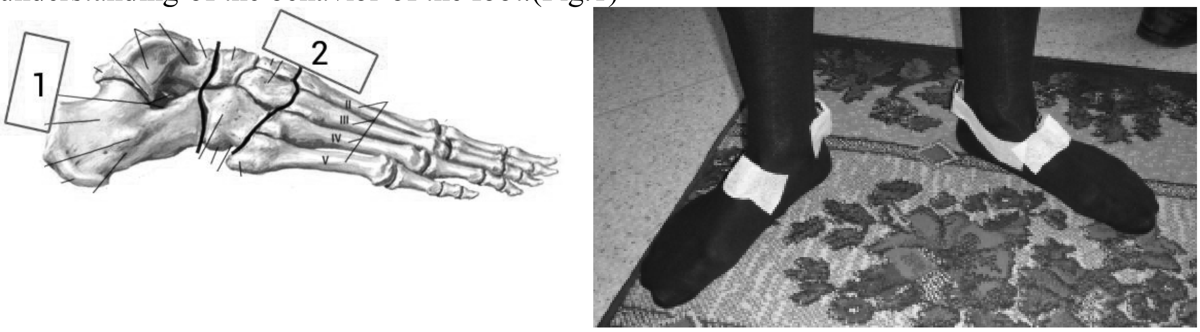
CHOOSING A LOCATION

It's important to choose mounting places of the measuring modules. The basic object of the musculoskeletal system can be considered as bone skeleton. Layers of the muscles, ligaments, skin and fat affect the data on parameters of the bone skeleton motion. Selecting the attachment places we must minimize that impact as possible.

In particular, we can use the anthropometric points on the body that are used in medical practice. Typically, this is the place where the skin adjacent to the bone without the other layers or these are very thin. They are used to determine the anthropometric parameters of the person (eg, length of arms).

Gait parameters include description of the step. It should be noted that the sensor is accelerometer. Most marked acceleration occurs on device when measuring modules installed

on the foot. The data were compared with the modules installed on the foot, leg, hip and pelvis of man to understand this.
Foot contacts with the surface, and it takes the impact during walking. It has a complex structure (Netter, 1997), but its parts do not make complex motion during walking. The measurement modules are installed on the heel and instep of the foot for a more complete understanding of the behavior of the foot.(Fig.1)



A) B)

Fig. 1 Mounting places of the measurement modules (B) and scheme of mounting (A)

This allows complete control over the interaction between the surface and the foot while the foot shifts the mass center during one period of the gait cycle. There is only a thin layer of skin besides the sensor and the bone in this area, which minimizes noise in the data.

THE MEASUREMENT PROCEDURE

Modules will be installed per person in selected locations. The person performs the following tasks during experiment:

- Standing;
- Walking straight;
- Turning around;
- Walking in the opposite direction in a straight line;
- Standing.

Measurement modules transmit information about the movement of the body. This means that installed on the foots four measuring modules will provide data about motion by 12 channels (projections of the acceleration of the axes X, Y, Z). Person repeats a task 10 times. Measurement modules wasn't removed during the experiment.

ESTIMATION OF OBTAINED DATA

It’s very important to assess repeatability motion data. If the plots have good repeatability, the measurement technique can be used to analyze the motion parameters. In all obtained plots instant accelerations increasing was clearly visible, which shows the foot contact with the surface. The interval between such increases equals to the step cycle. For comparison steps cycles on each plot 2 cycles was allocated. Plots of the step cycle overlap (Fig. 2).

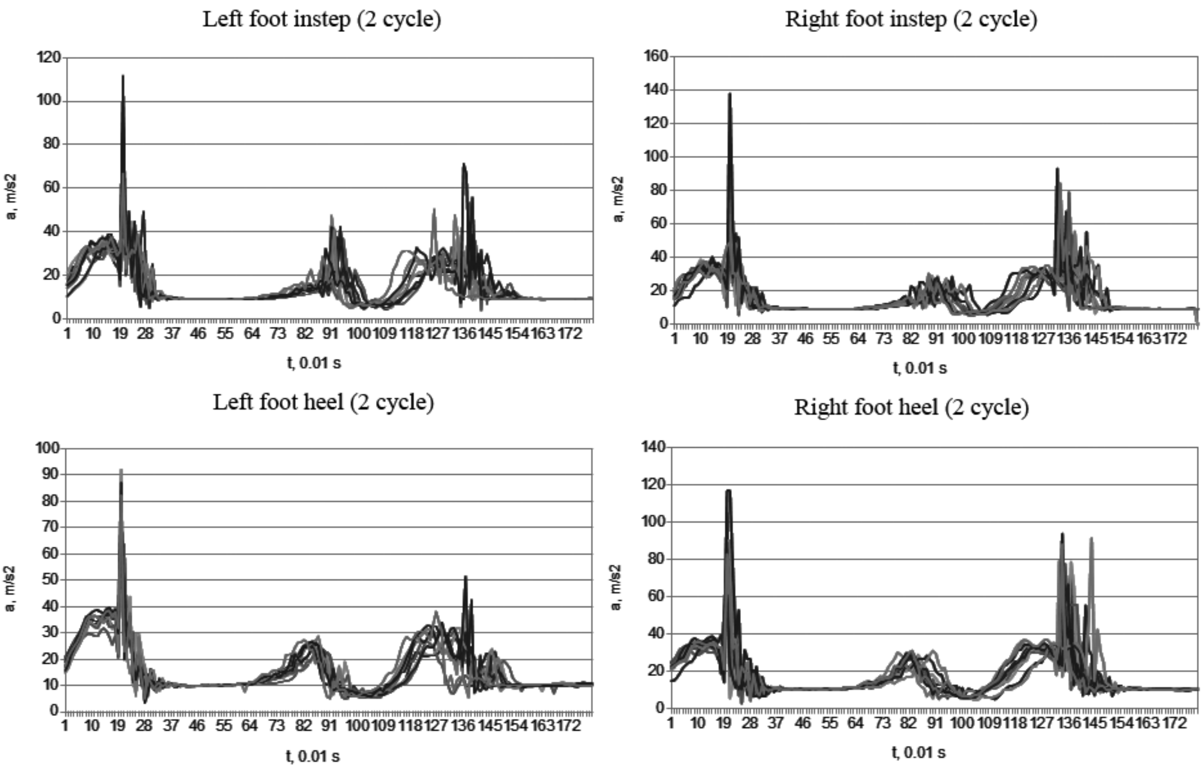


Fig. 2 Repetition of movement data

The plots shows that spread of the step cycle periods is 0.1 seconds. Average step cycle is 1.2 seconds. It is important to note that in the measured data only two cycles can be identified. One of them is a cycle of acceleration, the second is cycle of stopping. If the experiment people will do more than 3 steps, then it will be possible to analyze the cycle of stable motion. This can reduce the error of step cycle period measurement. However we can say that the repeatability of data is good.

SIMPLE MODEL OF THE MOTION

There are three step phases (Ayyappa, 1997):

- Single limb - one foot contacts with floor;
- Double limb - two foots contact with floor;
- Swing.

There is a more detailed description of these phases. This description focuses on the work of the various movements of the musculoskeletal system parts. In this case, the following steps will be phase (Kapandji, 2010):

1. Start moving forward pendulous limb
2. Initial contact of the heel with the bearing surface
3. Vertical support on one foot, the sole is fully in contact with the floor
4. Disequilibrium ahead
5. First leading thrust ahead before footing for two legs
6. Second leading thrust acting on the bearing leg in full extension, while the pendulous limb is going to step on the floor

7. Start oscillation when another limb becomes carrier
8. Oscillation of the front limb
9. Landing of oscillating muscle

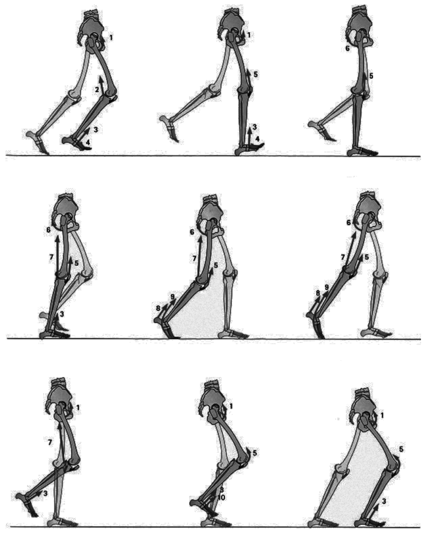


Fig. 3 Graphical representation of step cycle

Analyzing step phases two key events can be noted: impact on the heel, instep gap. During impact on the heel the human center of mass moves right and down. The impulse of a falling body through the feet passed the floor. If the floor is solid under these conditions, the velocity of the foot drops to zero. The module sensors detect this like a significant increase of the instantaneous acceleration, and after this it decreases, when the energy transferred to the floor. During this event changing of the acceleration value should be the greatest over the duration of the step cycle.
Then the man moves the foothold from heel to toe of the foot. When the foothold is at the toe, a man pushes using his foot. Thus, he fully takes a foothold on the another leg. So, first human extends the ankle, starting from the floor. Then there is a gap of toe from the floor, after which the joint unbends as the sural muscle works on.

ANALYSIS OF OBTAINED DATA

The plots of the data from sensors on the heel and instep of the foot are shown in Fig. 4. Below, diagram shows forces acting on the leg at the same time.
Five stages of movement are identified. The following definitions are used: the force of gravity affects the human center of mass (mg), reaction force (N), the force of the foot (F), the moments of forces which change the position of human leg during movement (M1, M2, M3).
In the first stage floor reaction force occurs at the heel after the contacting with the right foot. The body moves under the influence of the interaction of gravity (mg), repulsive forces left leg (N) and the force moment of hip (M1). Also human trunk muscles are involved in the movement, but they are not considered here. As a result the center of foothold moves from heel to the center of the foot with simultaneous falling of the instep to the floor.
In the second phase the foothold center is situated in the middle of the foot, it rests on the floor. The body moves mostly by inertia, while legs forces opposes (F) gravity (mg).

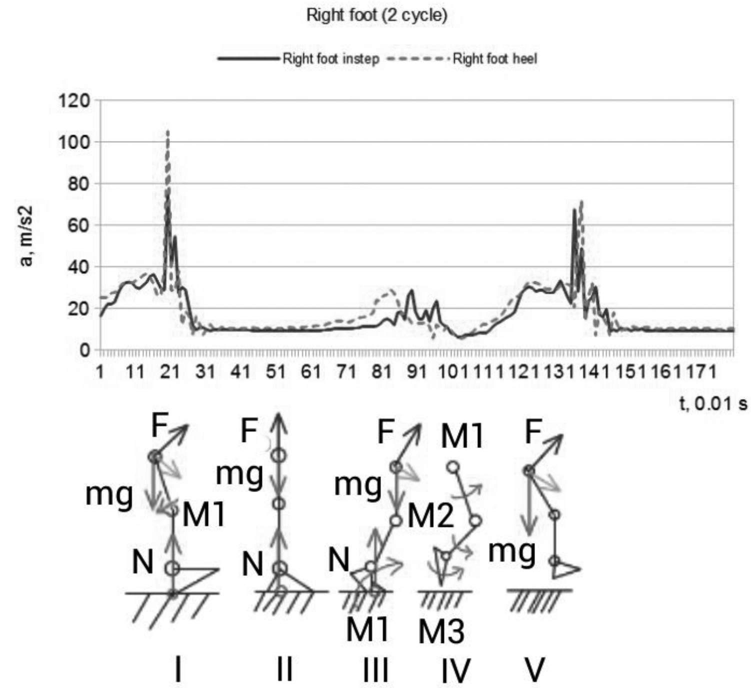


Fig. 4 Connection between data and theory of movement

In the third stage, a human pushes right leg from the floor by force F. The center of the foothold goes from the middle to the toe of foot with simultaneous separation of the foot from the floor. The movement is caused by the interaction between push force F of his right foot and the force of gravity mg.

In the fourth stage foot moves, at first, by inertia, and then it moves under the influence of hip extensor strength (M1), knee (M2) of the joints and the flexor strength of ankle (M3) of the joint. Whole, the load is transferred to the left leg.

In the fifth stage the foot falls to the floor due to gravity (mg) and push the left leg (F).

Plot shows, the data from the devices can determine the intervals of each of the stages, and they correspond to the descriptive model. This is a very simplified model, but motion diagram is complex. This suggests that there are many factors which must be considered. The most important is the impact of Coriolis force because sensors measure relative to the inertial coordinate system. The main objective of modeling is to restoration diagram of the motion using the mathematical model.

THEORETICAL BASE OF MEASURMENTS

Let we take as example 3-link manipulator simulating human leg (Fig.5) and determine angles $\varphi_1, \varphi_2, \varphi_3$.

The movement of C-point (point of measuring device installation) can be described with eq.1:

$$\begin{pmatrix} X_C(t) = a_0 + a_1 t^3 + a_2 t^2 + a_3 t = a_0 - b_0 t \\ Y_C(t) = d_0 + d_1 t^3 + d_2 t^2 + d_3 t = d_0 - c_0 t \end{pmatrix}, \text{ where } \begin{pmatrix} b_0 = -(a_1 t^2 + a_2 t + a_3) \\ c_0 = -(d_1 t^2 + d_2 t^1 + d_3) \end{pmatrix}$$

(1)

Let we deal that al the process lasts for 1 second.

In initial moment of time (t=0):

$$\phi_1 = \phi_0 + \omega_0 t + \varepsilon_0 \frac{t^2}{2}\ , \tag{2}$$

$$\dot{\phi}_1 = \omega_0 + \varepsilon_0 t\ , \tag{3}$$

$$\ddot{\phi}_1 = \varepsilon_0\ . \tag{4}$$

Than we find values of angles $\varphi_1, \varphi_2, \varphi_3$, in different moments of time, angular velocities $\dot{\varphi}_1, \dot{\varphi}_2, \dot{\varphi}_3$ and angular acceleration $\ddot{\varphi}_1, \ddot{\varphi}_2, \ddot{\varphi}_3$.

For every position of mechanism the following vector relationships hold (Fig.5).

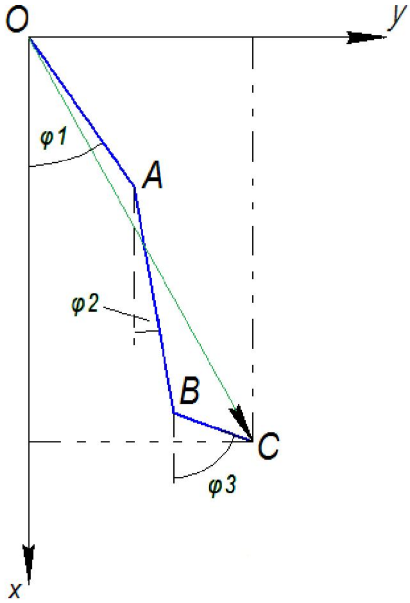


Fig. 5 Position of manipulator`s link and the summing vector

¿ , (5)

¿ , (6)

where OA – the distance between hip and knee joints, AB – the distance between knee and ankle joints, BC – the distance between ankle joint and point of measuring device installation. Eq.7,8 are constraining equations for system. After that we project them onto coordinate axis.

$$\begin{cases} X_B = OA\cos\varphi_1 + AB\cos\varphi_2 \\ Y_B = OA\sin\varphi_1 + AB\sin\varphi_2 \end{cases} \tag{7}$$

$$\left\{ \begin{array}{l} X_C = OA\cos\phi_1 + AB\cos\phi_2 + BC\cos\phi_3 \\ Y_C = OA\sin\phi_1 + AB\sin\phi_2 + BC\sin\phi_3 \end{array} \right\} \tag{8}$$

where
$$|\overline{OC}| = const;$$
$$|\overline{AB}| = const;$$
$$|\overline{BC}| = const.$$

We find first and second time derivatives. As a result, we obtain the first differential algebraic equation for the unknown velocities $\dot{\varphi}_1, \dot{\varphi}_2, \dot{\varphi}_3$:

$$\begin{cases} \dot{X}_B = -OA\sin\varphi_1\dot{\varphi}_1 - AB\sin\varphi_2\dot{\varphi}_2 \\ \dot{Y}_B = OA\cos\varphi_1\dot{\varphi}_1 + AB\cos\varphi_2\dot{\varphi}_2 \end{cases} \tag{9}$$

$$\begin{Bmatrix} \dot{X}_C = -OA\sin\phi_1\dot{\phi}_1 - AB\sin\phi_2\dot{\phi}_2 - BC\cos\phi_3\dot{\phi}_3 \\ \dot{Y}_C = OA\cos\phi_1\dot{\phi}_1 + AB\cos\phi_2\dot{\phi}_2 + BC\cos\phi_3\dot{\phi}_3 \end{Bmatrix} \tag{10}$$

After the second differentiation we obtain two systems of algebraic equations connecting angular accelerations $\ddot{\varphi}_1, \ddot{\varphi}_2, \ddot{\varphi}_3$:

$$\begin{cases} \ddot{X}_B(0) = -OA\cos\varphi_1(0)(\dot{\varphi}_1(0))^2 - AB\cos\varphi_2(0)(\dot{\varphi}_2(0))^2 - OA\sin\varphi_1(0)\ddot{\varphi}_1(0) - AB\sin\varphi_2(0)\ddot{\varphi}_2(0) \\ \ddot{Y}_B(0) = -OA\sin\varphi_1(0)(\dot{\varphi}_1(0))^2 - AB\sin\varphi_2(0)(\dot{\varphi}_2(0))^2 + OA\cos\varphi_1(0)\ddot{\varphi}_1(0) + AB\cos\varphi_2(0)\ddot{\varphi}_2(0) \end{cases} \tag{11}$$

$$\begin{Bmatrix} \ddot{X}_C = -OA\cos\phi_1(\dot{\phi}_1)^2 - AB\cos\phi_2(\dot{\phi}_2)^2 - BC\cos\phi_3(\dot{\phi}_3)^2 - \\ \ddot{Y}_C = -OA\sin\phi_1(\dot{\phi}_1)^2 - AB\sin\phi_2(\dot{\phi}_2)^2 - BC\sin\phi_3(\dot{\phi}_3)^2 + \end{Bmatrix}$$

$$\begin{matrix} -OA\sin\phi_1\ddot{\phi}_1 - AB\sin\phi_2\ddot{\phi}_2 - BC\sin\phi_3\ddot{\phi}_3 \\ +OA\cos\phi_1\ddot{\phi}_1 + AB\cos\phi_2\ddot{\phi}_2 + BC\cos\phi_3\ddot{\phi}_3 \end{matrix} \tag{12}$$

The values $\dot{X}_C, \dot{Y}_C, \ddot{X}_C, \ddot{Y}_C$ are determined by differentiating point of the measuring device installation:

$$\begin{pmatrix} \dot{X}_C = -b_0, & \ddot{X}_C = -(2a_1 t + a_2) \\ \dot{Y}_C = -c_0, & \ddot{Y}_C = -(2d_1 t + d_2) \end{pmatrix}. \tag{13}$$

For initial moment of time $t = t_0 = 0$, we have:

$$\begin{Bmatrix} -b_0 = -OA\sin\phi_1(0)\dot{\phi}_1(0) - AB\sin\phi_2(0)\dot{\phi}_2(0) - BC\sin\phi_3(0)\dot{\phi}_3(0) \\ -c_0 = OA\cos\phi_1(0)\dot{\phi}_1(0) + AB\cos\phi_2(0)\dot{\phi}_2(0) + BC\cos\phi_3(0)\dot{\phi}_3(0) \end{Bmatrix}. \tag{14}$$

$$\begin{cases} \dot{X}_B(0) = -OA\sin\varphi_1(0)\dot{\varphi}_1(0) - AB\sin\varphi_2(0)\dot{\varphi}_2(0) \\ \dot{Y}_B(0) = OA\cos\varphi_1(0)\dot{\varphi}_1(0) + AB\cos\varphi_2(0)\dot{\varphi}_2(0) \end{cases} \tag{15}$$

For determination $\varphi_2(0)$ and $\varphi_3(0)$ we use Eq.8

$$\begin{Bmatrix} a_0 = OA\cos\phi_1(0) + AB\cos\phi_2(0) + BC\cos\phi_3(0) \\ d_0 = OA\sin\phi_1(0) + AB\sin\phi_2(0) + BC\sin\phi_3(0) \end{Bmatrix}, \tag{16}$$

Let we define: $\begin{matrix} a_0 - OA\cos\varphi_1(0) = A_0 \\ d_0 - OA\sin\varphi_1(0) = B_0 \end{matrix}$

$$\begin{cases} AB\cos\varphi_2(0) + BC\cos\varphi_3(0) = A_0 \\ AB\sin\varphi_2(0) - BC\sin\varphi_3(0) = B_0 \end{cases}. \tag{16'}$$

Solve the system of Eq.16', squaring and add both parts of the system of equations:

$$AB^2\left[\cos^2\varphi_2(0) + \sin^2\varphi_2(0)\right] + BC^2\left[\cos^2\varphi_3(0) + \sin^2\varphi_3(0)\right] +$$

$$+2AB\cdot BC\left[\cos\varphi_2(0)\cos\varphi_3(0) - \sin\varphi_2(0)\sin\varphi_3(0)\right] = A_0^2 + B_0^2$$

$$\cos\left[\varphi_2(0) + \varphi_3(0)\right] = \frac{A_0^2 + B_0^2 - (AB)^2 - (BC)^2}{2AB\cdot BC}$$

Define $Z_0 = \dfrac{A_0^2 + B_0^2 - (AB)^2 - (BC)^2}{2AB\cdot BC}$

$$\varphi_2(0) + \varphi_3(0) = \arccos(Z_0)$$

Substituting into Eq.16'

$$AB\left[\cos\varphi_2(0)\sin\varphi_3(0) + \sin\varphi_2(0)\cos\varphi_3(0)\right] = A_0\sin\varphi_3(0) + B_0\cos\varphi_3(0)$$

$$AB\sin\left[\varphi_2(0) + \varphi_3(0)\right] = \sqrt{A_0^2 + B_0^2}\,\sin\left[(\alpha + \varphi_3(0)\right]$$

$$\alpha = arctg\frac{B_0}{A_0}$$

$$AB\sin\left[\arccos(Z_0)\right] = \sqrt{A_0^2 + B_0^2}\,\sin\left[(\alpha + \varphi_3(0)\right]$$

$$\sin\left[(\alpha + \varphi_3(0)\right] = \frac{AB\sin\left[\arccos(Z_0)\right]}{\sqrt{A_0^2 + B_0^2}}$$

$$\varphi_3(0) = \frac{\arcsin\left[AB\sin\left[\arccos(Z_0)\right]\right]}{\sqrt{A_0^2 + B_0^2}} - \alpha, \tag{17}$$

$$\varphi_2(0) = \arccos(Z_0) - \varphi_3(0). \tag{18}$$

Now we can find $X_B(0)$ and $Y_B(0)$, knowing $\phi_2(0)$ from system of Eq.7.
Substituting found values $\phi_2(0)$ and $\phi_3(0)$ in Eq.14,15, it is possible to find derivatives $\dot\varphi_2(0), \dot\varphi_3(0), \dot X_B(0), \dot Y_B(0)$:

$$\begin{cases} AB\sin\varphi_2(0)\dot\varphi_2(0) + BC\sin\varphi_3(0)\dot\varphi_3(0) = b_0 - OA\sin\varphi_1(0)\dot\varphi_1(0) \\ AB\cos\varphi_2(0)\dot\varphi_2(0) - BC\cos\varphi_3(0)\dot\varphi_3(0) = -c_0 - OA\cos\varphi_1(0)\dot\varphi_1(0) \end{cases}, \tag{19}$$

Knowing $\dot\varphi_2(0), \dot\varphi_3(0)$, we find $\dot X_B(0), \dot Y_B(0)$:

$$\begin{cases} \dot X_B(0) = -OA\sin\varphi_1(0)\dot\varphi_1(0) - AB\sin\varphi_2(0)\dot\varphi_2(0) \\ \dot Y_B(0) = OA\cos\varphi_1(0)\dot\varphi_1(0) + AB\cos\varphi_2(0)\dot\varphi_2(0) \end{cases}.$$

Than solve the system of equations using MATLAB (Appendix 4).
For initial t=0, Eq.11,12 are:

$$\begin{cases} 0+OA\cos\varphi_1(0)(\dot{\varphi}_1(0))^2+AB\cos\varphi_2(0)(\dot{\varphi}_2(0))^2+BC\cos\varphi_3(0)(\dot{\varphi}_3(0))^2 = \\ 0+OA\sin\varphi_1(0)(\dot{\varphi}_1(0))^2+AB\sin\varphi_2(0)(\dot{\varphi}_2(0))^2-BC\sin\varphi_3(0)(\dot{\varphi}_3(0))^2 = \end{cases}$$

$$\begin{aligned} &= -OA\sin\varphi_1(0)\ddot{\varphi}_1(0)-AB\sin\varphi_2(0)\ddot{\varphi}_2(0)-BC\sin\varphi_3(0)\ddot{\varphi}_3(0) \\ &= OA\cos\varphi_1(0)\ddot{\varphi}_1(0)+AB\cos\varphi_2(0)\ddot{\varphi}_2(0)-BC\cos\varphi_3(0)\ddot{\varphi}_3(0) \end{aligned} \tag{20}$$

After that we use the program to calculate the MATLAB (Appendix 4), from which we get $\ddot{\varphi}_2(0), \ddot{\varphi}_3(0)$.

$$\begin{cases} \ddot{X}_B(0) = -OA\cos\varphi_1(0)(\dot{\varphi}_1(0))^2-AB\cos\varphi_2(0)(\dot{\varphi}_2(0))^2-OA\sin\varphi_1(0)\ddot{\varphi}_1(0)-AB\sin\varphi_2(0)\ddot{\varphi}_2(0) \\ \ddot{Y}_B(0) = -OA\sin\varphi_1(0)(\dot{\varphi}_1(0))^2-AB\sin\varphi_2(0)(\dot{\varphi}_2(0))^2+OA\cos\varphi_1(0)\ddot{\varphi}_1(0)+AB\cos\varphi_2(0)\ddot{\varphi}_2(0) \end{cases}$$

Expanding in a Maclaurin series, we obtain:

$$\varphi_2(1) = \varphi_2(0)+\dot{\varphi}_2(0)\Delta t+\ddot{\varphi}_2(0)\frac{\Delta t^2}{2}, \tag{21}$$

$$\varphi_3(1) = \varphi_3(0)+\dot{\varphi}_3(0)\Delta t+\ddot{\varphi}_3(0)\frac{\Delta t^2}{2}. \tag{22}$$

Taking into attention that $\varphi_1(t)$ is known from initian conditions, we can get $\varphi_1(1)$

$\varphi_1(1) = \varphi_0+\omega_0\Delta t+\dfrac{\varepsilon\Delta t^2}{2}$, substituting in Eq.10 and getting:

$$\begin{cases} AB\sin\varphi_2(1)\dot{\varphi}_2(1)+BC\sin\varphi_3(1)\dot{\varphi}_3(1) = b_0-OA\sin\varphi_1(1)\dot{\varphi}_1(1) \\ AB\cos\varphi_2(1)\dot{\varphi}_2(1)-BC\cos\varphi_3(1)\dot{\varphi}_3(1) = -c_0-OA\cos\varphi_1(1)\dot{\varphi}_1(1) \end{cases}$$

Using the program to calculate the MATLAB (Appendix 4), we find $\dot{\varphi}_2(1), \dot{\varphi}_3(1)$.
Similarly, to find the following approximation for the acceleration $\ddot{\varphi}_2(1), \ddot{\varphi}_3(1)$ we substitute into Eq. 12, than Eq. 20 and so on.
We build the scheme of positions of links using matlab (Appendix 5).
As a result we have figures close to Fig. 2 and Fig. 4.
The degree of cycles repetition depends on quality of made measurements and similarity of steps.

RESULTS AND CONCLUSIONS

The main goal of work was getting the same theoretical and practical results. It confirms correctness of created mathematical model.

Moreover, a technique of using inertial measurement devices for measuring human motion to get some numerical results was invented. The use of this technique on practice demonstrated that it can be used to obtain an objective parameter describing the motion of the person.

Continuation of this work is directed to an active rehabilitation with the help of high-tech device – motor driven bandage. The mathematical model can be used as the control element of the bandage. Its main task is to predict human movement to control the load on the target joint.

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