Walk Optimization for Hexapod Walking Robot

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Abstract: Our research is a part of the process of building the new walking hexapod robot. The marginal parameters affecting the quality of robot drive is discussed in detail in this article. Such parameters are the following: the division of the arm's pathway; the application of FIR filter for the filtering the robot foot pathway; and in Fuzzy control the rpm error and maximum value of total current consumption. The analyses of these parameters enable us to determine the optimal drive engines, as well as the drive software parameters.

Keywords: optimization the leg trajectory, hexapod walke, FIR filter, optimal torque

1 Introduction

Our research is a part of the process of building the new walking hexapod robot. The previously-built "Szabadka" hexabod walker, its development and problems related to its development were all described in the publications [1,2]. The building of the complete kinematic and dynamic model of the current robot is published in [3,4]. In realization the new robot is important problem is building and testing the full kinematic and dynamic model [7] of robot in Matlab/Simulink environment. The first step when in constructing a real robot is the insight from the simulation results. Therefore we should build a perfect model. Our research is a part of the process of building the new walking hexapod robot. Our robot architecture has 18 degree of freedom, and about 5kg weight. The issue of the robot's drive soft-computing using small power intake microcontrollers is discussed in [5]. The robot in image [2] shows all relevant parameters in the building of the model.

The low-power DC micro motors are widely used, especially in the field of robotics and mechatronics. We choose this micro motor from FaulHaber [6].

The marginal parameters affecting the quality of robot drive is discussed in detail in this article. Such parameters are the following: the division of the arm's pathway; the application of FIR filter for the filtering the robot foot pathway; and in Fuzzy control the rpm error and maximum value of total current consumption.

The analyses of these parameters enable us to determine the optimal drive engines, as well as the drive software parameters.

2 Simulation Model

The current simulation model is acceptable if the results carry information even given a certain error. Often it is enough if the range of signals or the spatial and temporal range can be seen, then it is possible to draw conclusions, which direction to move towards.

This system has many parameters, but basically these can be divided into hardware and software parameters.

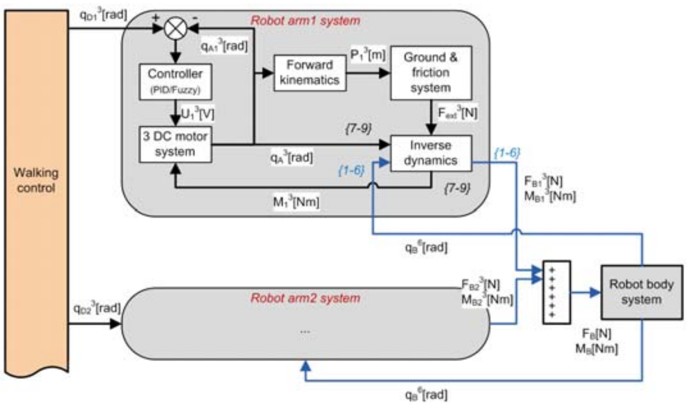

Figure 1

Hexapod walking robot total kinematic and inverse dynamic model

The HW parameters for a hexapod robot can further be classified into:

- structural parameters
    - the shape and size of the robot's body and leg joints
    - the suspension points of the legs on the body
    - rotation end values of the legs
    - choice of spring and damper part
- engine parameters
    - choice of DC engines
    - choice of gears
    - choice of encoders
- electronics parameters
    - choice of microcontrollers
    - capacity of the batteries

Parameters of the control electronic software

- 1. engine layer – engine control parameters
    - sampling control
    - types of engine control (Fuzzy, Fuzzy-Neural, PID, PI, hybrid)
    - control parameters
        - in case of PID: P, I, D values
        - in case of Fuzzy: limits and shapes of membership functions, rules, calculation methods, etc…
- 2. trajectory layer - walking
    - speed of walking (in step/second)
    - method of walking (out of the 6 legs how many legs and lifted simultaneously, and in what order)
    - the arc shape of the lifted part (spline, ellipse, polyline)
    - length of a step
    - height of a step
    - temporal ration of the lifted period compared with the period on the ground
- 3. walking layer – some time in the future

The parameters of the system can only be chosen correctly, in fact optimized with the help of simulation, if one or more goals are set. Generally these goals are:

- achieving maximum speed of walking taking up as little electric energy as possible
- make the torques on the joints and gears, and the currents of the engines discursive and spiky as little as possible, and let their variation be as small as possible
- while walking, let the robot’s body acceleration be minimal in all 3 dimension directions
- make the robot function the same even with a greater load (a load of at least its own body weight)

Since the change of these parameters will influence the optimal values of the other parameters – that is, these are not independent parameters – that’s why the optimal parameter set is to be sought in the multi-parameter space. Naturally, these can be grouped, meaning that not all parameters have to be monitored at the same time, only those, that have a significant influence on each other.

Trying all the combination would take a very long time, and since our current simulink model is about 1500 times slower then running it on an ordinary computer, this means that simulating 1 second of robot walk takes about 25 minutes. If, thus, in one group there are 10 independent parameters, and for each we take 5 values, then it would take 12000 years to run all the combinations. Later on in the research the aim is to find suitable starting points and destinations, in order to run the optimizing algorithm we need greater performance equipment than we now have available.

Currently we are forced to test each parameter based on intelligent thinking. For example, it is not difficult to figure out that by rounding the leg-end walking path the sudden jolts in the joint can be decreased. Or a further example, if the fuzzy controller tries to suppress the change in current, the result will probably be an even softer controller, thus the change in current will also be smaller. Naturally, we must pay attention that this does not hurt our other goals, such as that the speed of the robot will decrease significantly, or it can't bear the weight, etc.

The walking algorithms determine the robot's movement, the load of the robot engine, the dynamics of power consumption, torque of the separate reductors, etc. In the case of hexapod items there are several basic types of walking. One is when during the walk 3 legs are always on the ground, and 3 are in the air, another type is when 4 legs are constantly on the ground and 2 legs are in the air, and the third type is when 5 legs are continuously on the ground, and only 1 leg is in the air. The following section will focus on three-legged walk.

3 Development of Walking on Three Legs

Walking on 3 legs means that out of the 6 six legs, 3 are always lifted together and the other 3 hold the up the robot. Thus moving consists of two cycles:

1. the robot is standing on the ground and pushes its legs number 1, 4, and 5 backwards
2. in a lifted-up position it moves legs no. 2, 3, and 6 forwards

Every leg makes the exact same path, only one group of legs is half a period delayed in time.

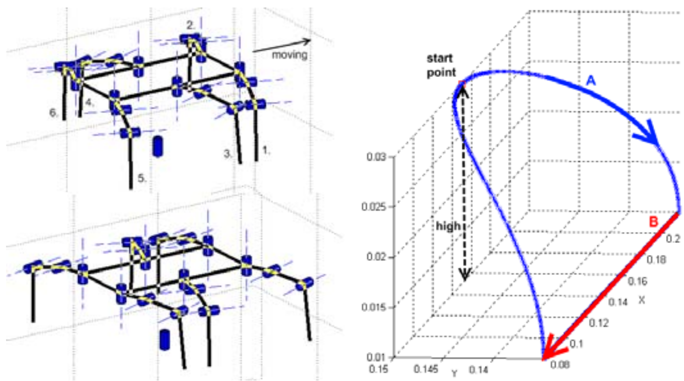

Figure 2
Wire-body model robot presenting walk, and image of trajectories on the separate arms

The pathway of the arms can be divided into section A and section B, as it can be seen in the image. Section A is when the arm is lifted up and that is the top part of the ellipse on the X-Z plane, which distorts the semi-circle in the direction of Y. The ground part of the pathway (B) is a straight, for forward motion. In the model following inverse calculation we gain the arcs for the three links which is filtered with a FIR lowpass filter (order 200) in order to round off the sharp corners. The following figure shows the effect of the FIR filter in the case of angle shift for the separate links, as well as shift of the tip of the arm due to various delays in the cases of oreder 10, 200, and 750. The images clearly show that with the use of the filter the sharp pathway transitions are rounded off, the result of which can be seen in the case sum of current and the distance covered. These will be discussed in a later part of the paper.

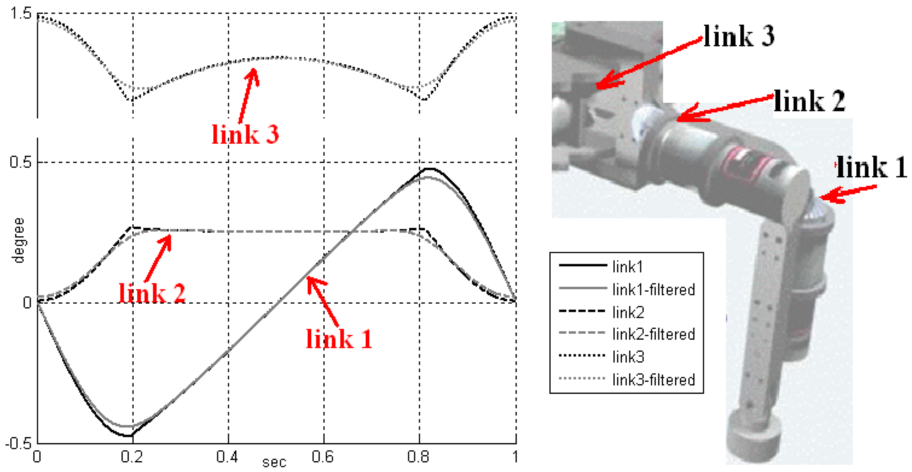

Figure 3

Presentation of robot link motion with and without filtering, and the numeration of the link

This section continues with the steadiness in the robot's walk. The time function and speed function of the robot body's motion is considered for the following cases:

- in **case 1** the time ratio of the two section of the arm pathway (A and B) is analyzed
- in **case 2** the delay of the FIR filter was changed
- in **case 3** the range of the first input (Error rotation) of the Fuzzy controller was changed
- in **case 4** the range of the second input of the Fuzzy controller was changed, this is the power value

The conclusion will describe the results reached with this method. The model will run using the parameters we thought best, and the results will be analyzed for the cases when the robot's weight together with the load is 1.5kg, 3.0kg, and 6.0kg.

In case 1. *the time ratio of the two section of the arm pathway (**A** and **B**) is analyzed*. In the analyzed cases the length of section ***A*** was changed in ratio to the entire length of the step. In the test the ratio of the length of section A to the whole was taken for the values 46, 50, 54, 58, 62, 66, 70 [%]. The aim was for the change of the robot's speed to be minimal during the walk because then it was expected that the current consuption, the torque on the gears and the changes of these would also be minimal. For the value of speed change to be minimized the forward motion has to be steady. If the A value is 46%, the maximum speed change in forward motion will be 0.32s, and for the value of 0.83s a change of rotation direction happens, which is a great load on the gear. If we look at the other end of the spectrum, then around 0.32s and 0.83s a major change in direction takes place, and the length of the pathway covered in 1s is also significantly decreased, which is not the aim. As the figures show, the value of 62% was deemed as best.

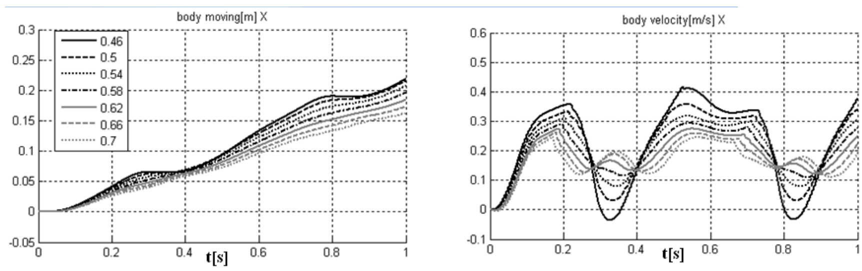

Figure 4
The time ratio of the two section of the arm pathway (A and B) for the change of speed and distance covered

In case 2. *We changed order of the FIR filter,* meaning the length of the filter, for the following values: 10, 50, 100, 150, 200, 300, 500, 750. The best result was provided by the order 200, because if the robot body's motion is considered in time, and the speed of the robot body's motion from the start to the end of 1s, the oscillation in negative direction around the 0.35s and 0.82s is the most expressed, if considering the speed diagram given the order longer than 200. However, with smaller order, e.g. 10 at the same time the change of speed is the greatest in positive direction, while the order of 200 brings the "smoothest" transition. If the robot body's motion in time is also considered parallel alongside the speed diagram, the smallest 1s time shift can be achieved with the order 750. The maximum distance covered and the best linear distance change is grouped from the order 10 to the 200. The argumentation as laid out above led us to determine that the FIR filter is the best with the order 200.

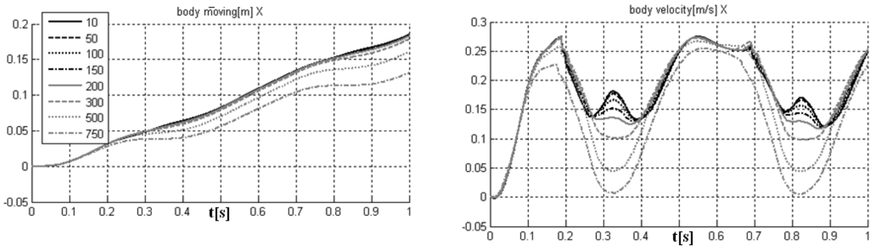

Figure 5
The effect of the order of the FIR filter on the pathway covered and temporal change of speed

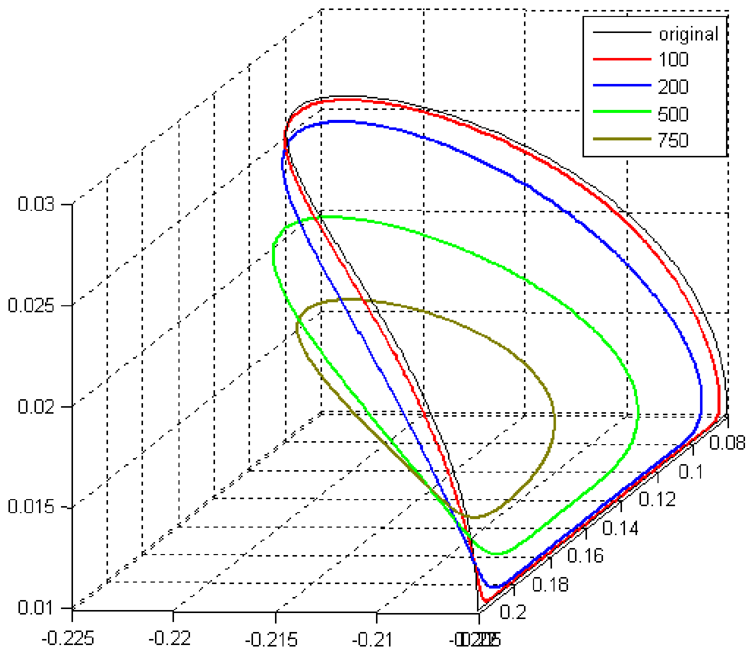

Figure 6
The effect of the order of the FIR filter on the pathway

In case 3. *the range of the first input (error rotation) of the Fuzzy controller was changed.* If the transition around zero (for the value 300) is take very narrowly, the speed will show the greatest changes. In the opposite case, if it is taken very widely (for the value 3000), then dynamics of change will decrease, which is to be expected, but the 20cm per second will decrease to 16cm of covered pathway. Taking into consideration also the current setup dynamics, the most optimal case is a value between 1000-1500. Given this value, the motion speed can be kept at maximum level.

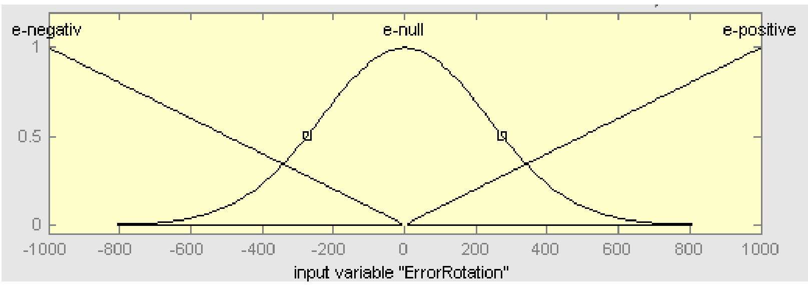

Figure 7
Presentation of error rotation Fuzzy membership function

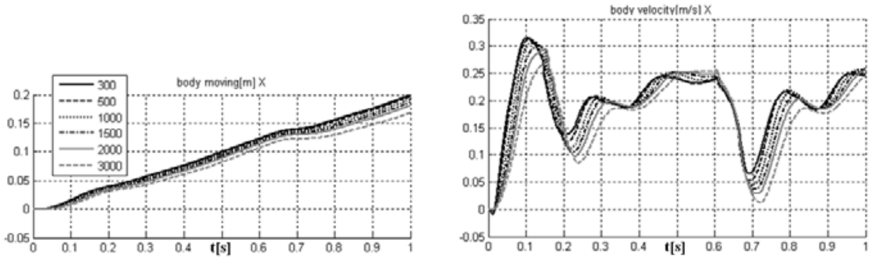

Figure 8
Choice of rotation speed limits for the pathway covered and the temporal speed change

In case 4. the range of the second input of the Fuzzy controller was changed, this is the total current consumption value. The limit of total current consumption value was changed ranging from 2.5A to 15A. In this case the aim is to achieve the smallest possible load on the battery during the forward motion of the robot. As the torque on the gears is also determined by the power setup, this leads to the conclusion that the change of speed for total currant consumption value must also be kept at the minimum. If the 2.5A limit is taken, then the robot can also cover 15 cm in the first second. If the current sum value is maximized at 15A, then the distance covered will be kept at 20cm, and the change in the robot’s speed will also be minimal. The greatest dynamics in changes take place in the range of 0.1s and a 0.7s, this is a compromise .

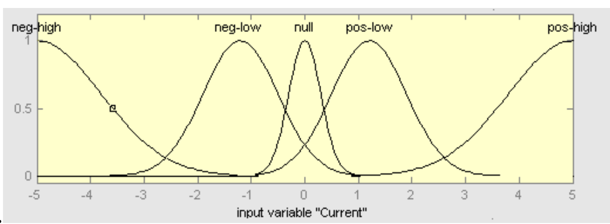

Figure 9
Presentation of the total current value fuzzy membership function

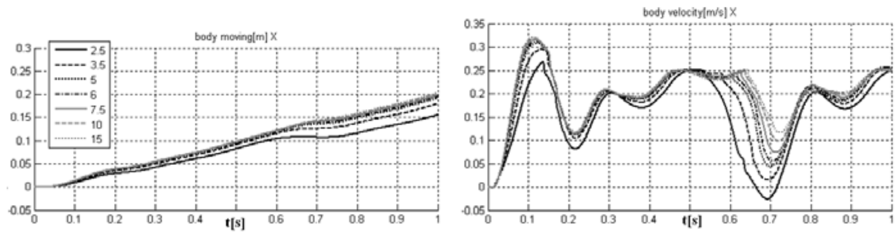

Figure 10
Effects of the choice of maximum current value limits on the pathway covered and temporal changes

4 Introduction

The robot motion and all dynamic results are observed within a given value of the robot's body mass. As it has been stated earlier in this work, the robot has to be able to carry twice its own body weight. The weight of the robot is 1.5 kg, the 6 arms weigh alltogether 3 kg, so the robot weighs a total of 4.5kg at least. If this weight is loaded on the body, the maximum body weight to be calculated with is 1,5+4,5=6kg. With maximum load the robot's entire weight is 6+3=9kg.

Following the optimization of the previous parameter using the best values, and maximum weight the following results were reached:

- Sum electric energy in 1 second: $E_e = 13.2$ [J]
- Robot moving in direction x along with start: $x = 0.195$[m]
- When the robot is walking horizontally, it takes $P_e = 13.2$[W] average performance, and moves forward 1 meter using 67,8[J] energy - Walking energy per meter: $E_{walk} = 67.8$[J/m]
- The taken total current $I_{average} = 3.68$[A], so the 3300[mAh] battery can sustain about 53 minutes of motion

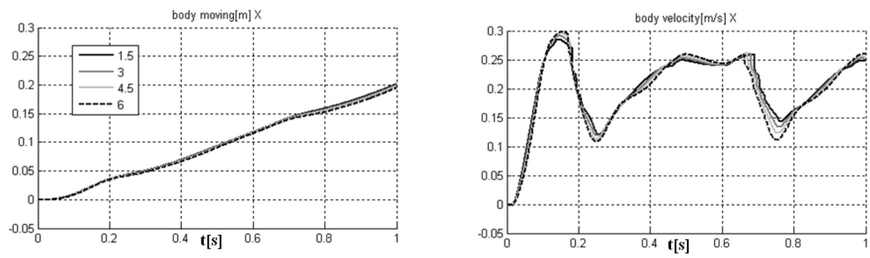

Figure 11
The effect of body mas of robot on the pathway covered and temporal change of speed

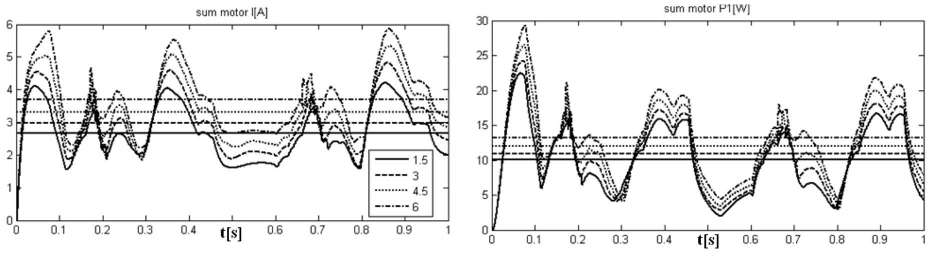

Figure 12
The effect of body mas on the total current and total power of robot

These results indicate the following things:

- \- if the taken electrical energy is transformed into equivalent potencial energy, then it would reach a height of 0,147[m] - Equivalent Z rise ($E_{pot} = m \cdot g \cdot h$): z = 0.147[m]
- \- horizontally it would reach 32% farther than if the equivalent electrical energy had been transformed into height - Rise-moving ratio: z/x = 132%. This value is also significant because this is how we express numerically the initial goal, namely to achieve the fastest possible walk using the least possible energy.

Simulations have been performed for four types of robot body weight: 1.5, 3, 4.5, 6[kg]. The robot's forward motion a given direction and its speed is shown in the Figure 12.

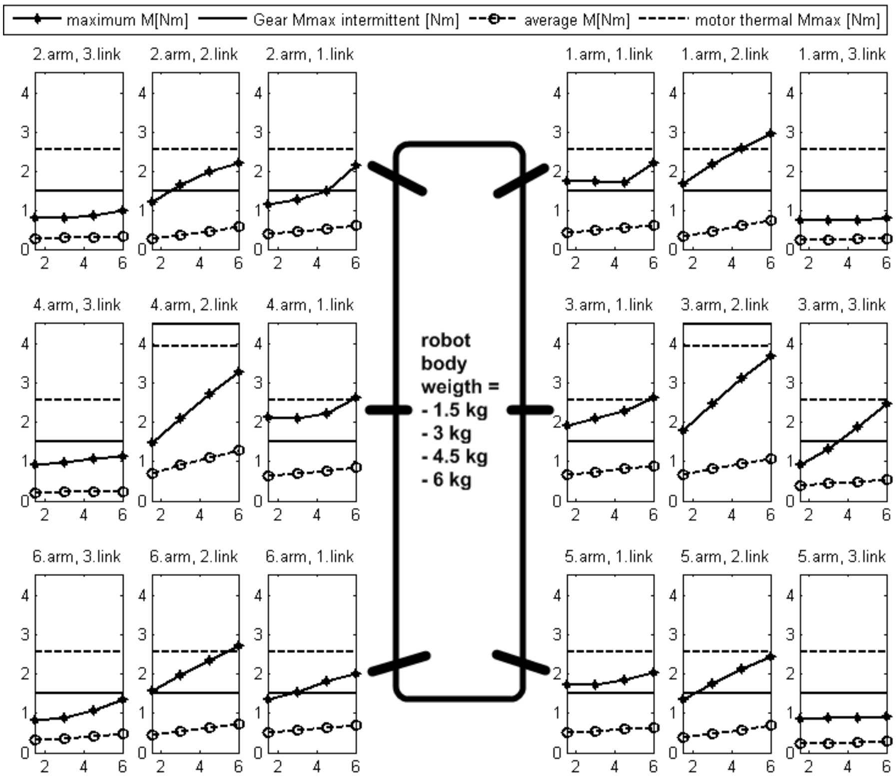

Figure 13

The maximum and average value for the torque in connection with the mas of robot's body

In the Figure 13 we can see the maximum and average value for the torque in connection with the mas of robot's body. The critial load of gears is drawn using horizontal lines for lifting, and the broken lines show the engine load in torque.

It is seen how the load of the second link is almost linear, but mostly on the two middle arms (3rd and 4th arms). The torque's temporal form shows that when walking on 3 arms, the two mentioned links are constantly under a 2[Nm]. Here the robot's body weight is 3kg, which is the value for no extra load Figure 14.

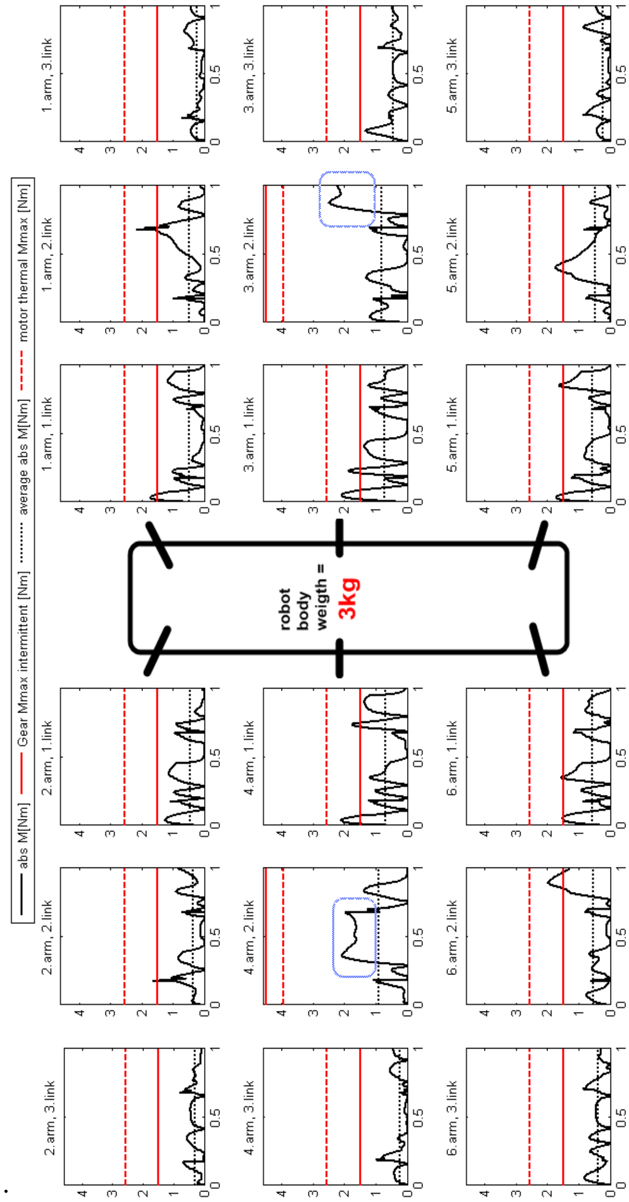

Figure 14
The torque of limks in connection with the 3kg mas of robot's body

As it can be seen from the previous sections, if there is a working model, then by running the simulation with different parameters, both the hardware as well as the software parameters can be optimized.

The model was mainly helpful in building the robot itself, as the choice of engine parts (motor, gear, encoder, battery) was vital. They had to endure the load, but it ought to be built using the smallest and lightest parts. The model showed that the carrier links of the central 2 arms have to have the stronger motor-gear pair, as they have to be able to lift the weight of half the robot when walking on three arms. Further, the simulation results were compared for calculating the walk's pathway, and so the most suitable parameters were chosen.

Naturally, not nearly all possibilities have been testes, e.g. if the robot does not use 3 but only 2 arms for walking. Numerous parameter combinations can be analyzed, many new ideas tested. These options are all open to us, only a small segment was realized and described in this article.

Acknowledgement

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