BMJ2K – walking octaped robot with 24 servomechanisms

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BMJ2K is a walking octaped robot designed for educational purposes. It uses walking algorithms based on biological observations. It's master control unit, ATmega128, communicates with a PC and transfers data to 8 slave ATmega8 microcontrollers. These are responsible for generating PWM signals for 24 servomechanisms which make robot walk.

1. Introduction

Nowadays, when automation and computerization have significant influence on civilization development, scientists are attempting to fulfill human needs. Replacing people with more efficient and precise automated devices becomes more and more frequent (let's take KUKA or FANUC manipulators for instance). Biorobotics can be mentioned as an example of strongly evolving discipline of automatic science. It's aim is to create machines based on patterns observed in nature. The biggest challenge for scientists is to create a humanoid robot which could communicate with people and also act out emotions.

Walking robots can be classified into following groups:

- one-legged robots,
- two-legged robots,
- four-legged robots,
- multiple-legged robots.

Two and four legged robots are most dominant, but multi-legged solutions offers better stability and easiness in moving on rough surfaces.

In this paper we present our proposition of design approach and construction details of octaped robot.

Next section says about solutions chosen in design path. Mechanical calculations and parts design was described in section III, also used software was listed there. Section IV specifies electronics layer of robot: circuits, connections etc. OpenGL mechanic visualizations software made in this project is depicted in section V. Section VI says about robot firmware and PC software development. Finally in section VII short conclusion was made and future plans were presented

2. Brief for design

The first step was design of the mechanical parts of the robot (see section III). Robot assembly drawings were made using CATIA V5 Dassault Systems. In order to verify the correctness of the construction we used DMU Kinematics module for kinematic analysis.

By using laser cutting techniques all the elements were prepared in order to assemble them with servos and other additional elements of construction. The next stage of work was the design and execution of the electronics.

With the use of EAGLE software from CadSoft, a printed circuit board was made which is responsible for controlling a single leg (lower layer of electronics) and a printed circuit board placed on the body of the robot (top layer of electronics), in charge of sending commands to the bottom layer of electronics and communication with the PC.

Based on the analysed algorithms of how walking robots move and the analysis of biological patterns[1,2], firmware was made for ATmega8 and ATmega128 microcontrollers. As communication bus needed to exchange data between the upper and the lower layer of electronics TWI bus was used, ensuring the free exchange of data in both directions.

In order to simulate walk of a robot and optimization of the kinematics – software visualization were created with Visual C ++ using OpenGL.

The next step was to develop a system of battery powering, together with the charging system, allowing the independent movement of the robot without the external power source. To solve this problem the lithium-ion cells from notebook computers were used.

In addition, in order to allow observation of the robot's current operating mode (a leg, which is currently moving, walking algorithm, etc.) graphical display with dimensions of 128 to 64 pixels was mounted on the body. By using this type of display it is possible to present any graphics or even simple animations.

3. Mechanical design

The design of eight-leg walking robot requires consideration of many parameters, such as the shape of the legs, number of degrees of freedom, or the type of electric drives used to set feet in motion. Only after a careful consideration of those issues, design of the robot could begin. There are many different solutions for the construction of a walking robot, particularly its legs. After analyse of the available solutions proposed in literature [1,2] and other projects of such robots [3] the decision was made to build legs with three degrees of freedom (Fig. 1). Such a solution can reach every point in the workspace, and do not limit the possibility of the movement of legs. This construction imitates the structure of insects' legs. The first segment of the leg is a hip (lat. *coxa*), second segment – a thigh (lat. *femur*), and the third segment – a shinbone (lat. *tibia*).

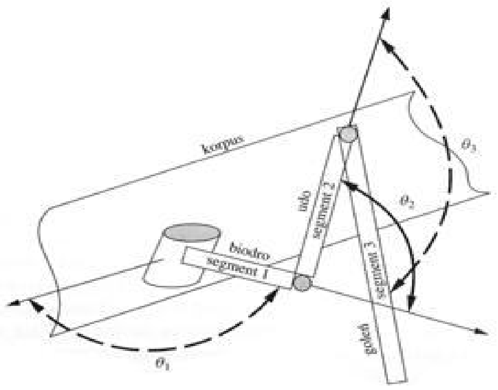

Fig. 1. Leg with three degrees of freedom

Another assumption taken into account during designing the shape of the robot's leg was the choice of driving elements. The best for such tasks were Hitec servos.

Their big advantage is the fact that their construction allows simple mounting to the leg structure. In the case of the shape of both body and legs there is quite a big flexibility of design, but it is necessary to take into account the above assumptions because it can have a significant influence on the range of motion of the leg.

Most servomechanisms are controlled with PWM signals. By modifying the duty cycle of a rectangular waveform, servo offset can be changed. The control signal must have the frequency of 50Hz (20ms period). Typically, servos position 0 is achieved with 1ms duty cycle set, the center position - 1.5ms and the maximum angle (of about 180deg) for 2ms.

Servos used in the solution are:

Hitec HS 422

- dimensions: 40.6 x 19.8 x 36.6[mm],
- weight: 45.5[g],
- torque (at 4.8/6[V]): 3.3 / 4.1 [kg/cm],
- speed (at 4.8/6[V]): 0.21 / 0.16 [sec/60°].

Hitec HS 475HB

- dimensions: 38.8 x 19.8 x 36 [mm],
- weight: 40[g],
- torque (at 4.8/6[V]): 4.4 / 5.5 [kg/cm],
- speed (at 4.8/6[V]): 0.23 / 0.18 [sec/60°].

Hitec HS 635

- dimensions: 40.6 x 19.8 x 38.8[mm],
- weight: 50[g],
- torque (at 4.8/6[V]): 5.0 / 6.0 [kg/cm],
- speed (at 4.8/6[V]): 0.18 / 0.15 [sec/60°].

During the robot design, decision was made that elements of the body and legs would be made from plexiglas. The advantages of this material are: relatively high strength and low weight compared to aluminium components of the same thickness. In addition, those elements require no painting and give a wide range of colours and thickness of the material.

Plexiglas used in this project was 3 mm thick - black (hips, thighs and body) and 4 mm – clear (tibia). The elements were cut with laser technology to ensure high accuracy and performance of elements. Despite the fact that the system CATIA V5 supports CNC equipment, it was difficult to find a company that would enable the cut of these elements on the basis of drawings made in this system. It was therefore necessary to make drawings in Corel Draw 9 on the basis of pre-made designs. Other elements of the robot, such as spacers and servomotors clamping systems, were made individually to ensure the needed parameters.

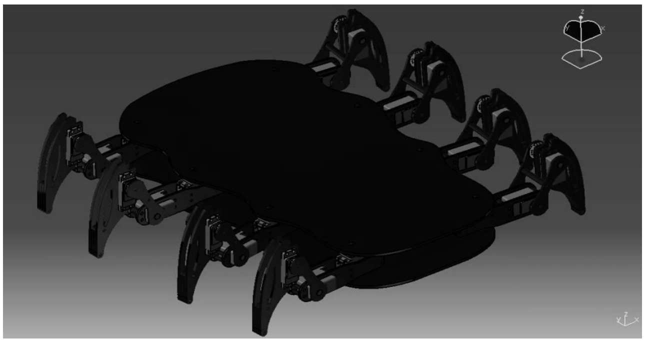

Fig. 2. CATIA design (screenshot)

4. Electronics

Problem of control each of the servos was solved by use one main master processing unit, that was responsible for receiving commands from the PC (like “go forward”) and transmitting proper commands (like “move the leg backward”) to slave units. Every slave unit controlling each leg sends adequate PWM control signals to each of legs servos.

According to above assumptions, one main PCB holding the master unit with peripherals was created. Additionally eight slave boards, one for each leg, was constructed.

The chosen microcontrollers were Atmel ATmega128 as the master unit and ATmega8 as slave units. Main advantage of those devices are low price, easiness in firmware development and debugging and availability on market. The RS-232 communication interface was chosen for data transmission between PC and master controller. TWI interface was used to transmit data between master and slave units. It was also important to find microcontrollers that have at least 3 independent PWM channels. ATmega8 can provide this functionality.

Although all elements used in the project (microcontrollers, servos and LCD) work at 5V operating voltage, an unit converting signals from an RS-232 serial port to TTL compatible signals was needed. The MAX232 circuit was used to enable PC – ATmega128 communication.

The fragment of main PCB is shown on fig. 3. The following slots were placed on the board:

- external power supply slot,
- ISP slots:
  - SPI,
  - JTAG,
- RS-232 port slot.

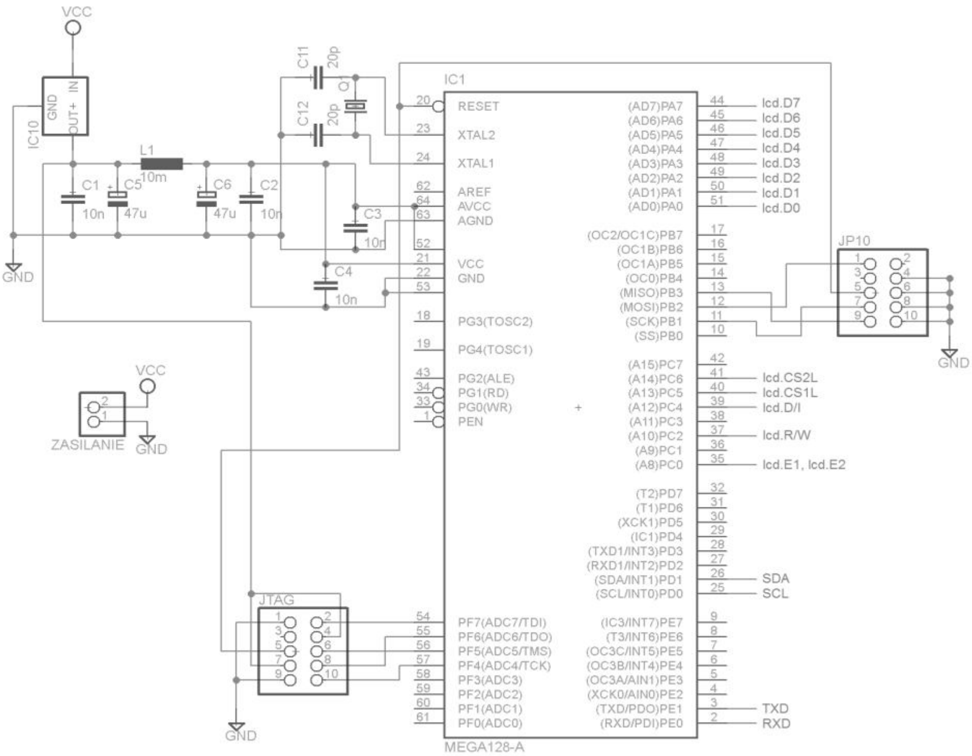

Fig. 3. Master unit schematic fragment

As for the slave board, the input signals are:

- VCC – regulated 5V supply voltage,
- GND – ground,
- SCL – clock signal of TWI,
- SDA – data signal of TWI.

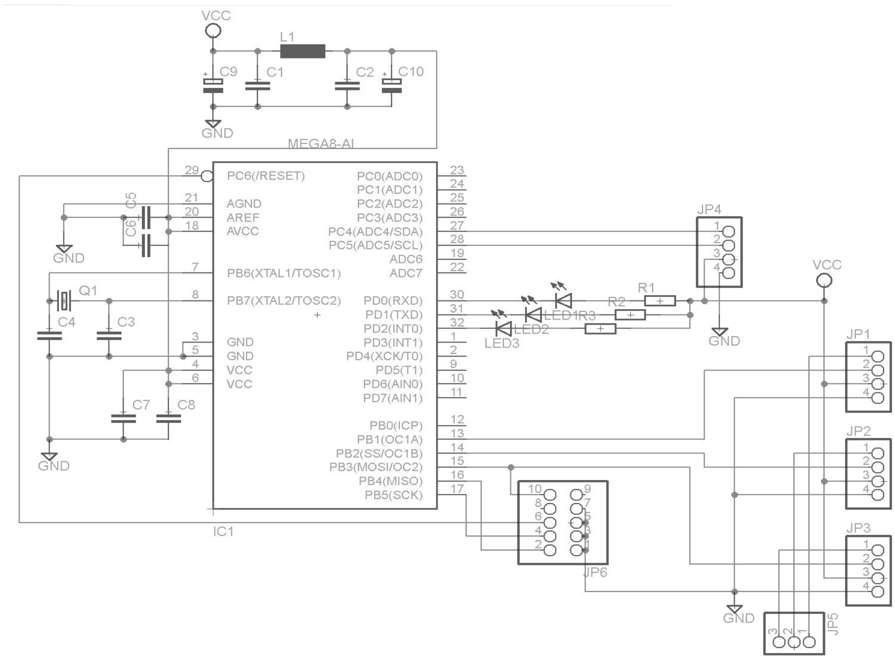

Fig. 4. Slave unit schematic

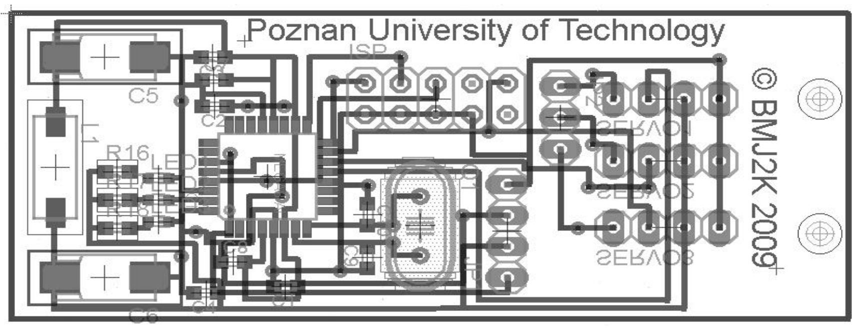

Fig. 5. Slave unit PCB project

5. OpenGL visualisationV

The application for visualization of BMJ2K's movement was developed using C++ programming language and OpenGL. Microsoft Visual Studio 2008 was used as an integrated development environment.

To create the visualization, both forward and inverse kinematics had to be computed for robot's body and each of it's legs.

Figure 6 shows the kinematic structure for a sample leg, described using modified Denavit-Hartenberg parameters, as shown in Table 1, a1, a2 and a3 are constant, while q1, q2 and q3 are the angles set by servos.

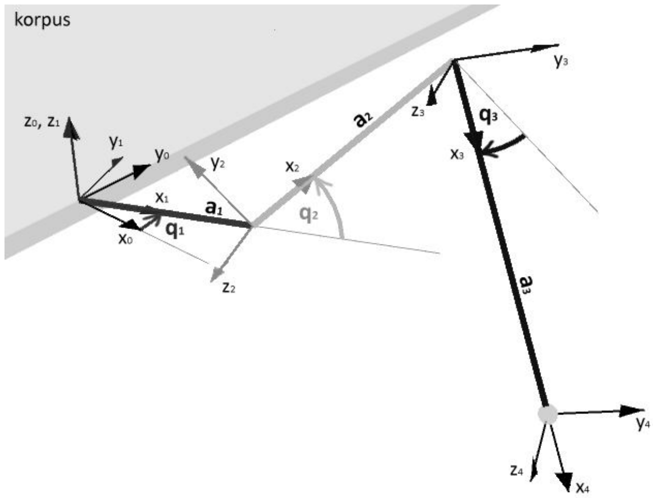

Fig. 6. Kinematic chain of a leg

Table 1. Modified Denavit-Hartenberg parameters

i	*ai*-1	*αi*-1	*di*	*θi*
1	0	0	0	q1
2	a1	90º	0	q2
3	a2	0	0	q3 – 90º
4	a3	0	0	0

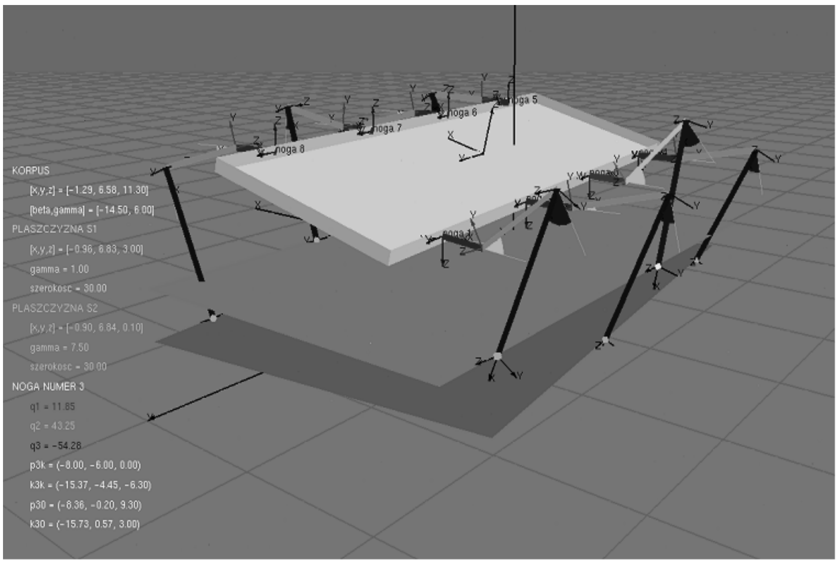

Fig. 7. Visualization of virtual surfaces

Application provides a visualization of robot motion, using different gait algorithms and allows user to change every servos angles for each leg. Information on each leg position (current angles, tip coordinates in both local and global systems) are displayed on the screen. Implementation of the inverse kinematics algorithm allows to move the tip along each of the three axes of the global system.

The latest modification of the program allows to define virtual surfaces (Fig. 7). Every leg tip can be bind to one surface. Robot movement is performed by changing the global position and orientation of chosen surfaces or robot's body, rather than by moving each leg separately.

6. Firmware and software development

The aim of microcontroller communication was to let user send control signals to master unit, which takes proper decisions and communicates with every slave unit using Two Wire Interface, giving them instructions where to move the leg. Slave unit is interpreting signals received from the master unit, generate appropriate PWM signals and send them to servos.

The function responsible for moving a leg takes each servo expected offset as a parameter, and completes the algorithm:

- find which servo has the biggest offset from current to expected position,
- find out in which direction the movement for each servo should be done,
- gradually change control signals from current position to the end,
- save new servos positions to global variables.

To analyze gait algorithms it is necessary to define some basic terms used to describe them. Gait period is the time needed to make one full sequence of leg movement. Duty factor is the ratio of time when a leg has the contact with surface to gait period. The relative phase of gait specifies the time between putting certain leg on the ground and the beginning of gait (or time when other leg touched the surface).

During movement, leg may be in two phases:

- leg touches the ground (retraction),
- leg is located above ground (protraction).

Studies made on arachnids *Neoscona Nautica* [2], specifically on scorpions *Hadrurus arizonensis* [3] allowed to recognize basic walk sequence of those animals. Analyze of photographs made to those arachnids it was found that at least four legs to support . It uses two groups of legs in this process (Fig. 8):

- first group: L1, R2, L3, R4,
- second group: R1, L2, R3, L4.

Those groups are used interchangeably. In first step first group is in motion and second one is support. In second phase groups change their functions (first is support, second is moving).

Each cycle of robots gait consists of eight phases of protraction and eight phases of retraction. Duty factors available for BMJ2K are as follows:

- 1/2 (shown on Fig. 8),
- 7/8,
- 6/7.

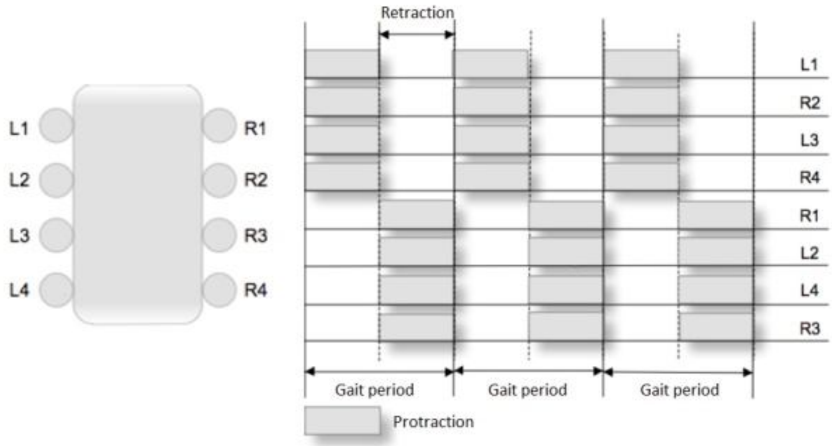

Fig. 8. Gait with duty factor ½

BMJ2K was designed to be controlled with a PC. To communicate between a computer and robot's master unit, RS-232 communication was used.

The user interface software for steering the robot was written in C++ using Microsoft Visual Studio 2008.

It allows user to choose between 3 duty factors (1/2, 7/8 and 6/7) and can make robot move in one of 8 directions. Properties of a serial port class can also be modified.

Fig. 9. User interface window

Program is working according to the algorithm:

- gait information is sent to ATmega128 through RS-232,
- microcontroller processes the information and begins to carry out the gait,
- after completing, a callback information is sent to the PC,
- if no errors occurred, next data packet is sent.

Pressing any button responsible for changing the direction of BMJ2K's movement changes the data sent to robot. According to this, the change in robot's movement is taking effect after another data packet is sent.

The robot can be supplied from a built-in battery system. The main restrictions when thinking of supplying BMJ2K were to obtain operating voltage between 7-9V (as an input for 5V voltage regulators) and be able to get the current value greater than 10A. 14.8V cells with capacity of 5200mAh, typically used to supply laptops, were used in this project.

In BMJ2K project the graphic LCD EA DIP128J-6N51W was used to display callback information from the robot. This device was chosen because of its many advantages:

- compact size,
- 128x64 pixels resolution,
- easiness of use (the unit is controlled by KS0108 driver),
- 5V operating voltage, compatible with project platform.

The main disadvantage of the LCD is that it doesn't have any font generator implemented by default. In order to display text messages on the screen, a custom font table was made, with character resolution 5x8 pixels.

7. Conclusion

Our proposal of octal robot construction was described, whole design path has been depicted, also solutions for many problems occurred during robot building and testing was presented. Robot was built and tested laboratory (Fig. 10). The main problem now is the weight of cells needed to power servos, but as the batteries made nowadays are getting lighter and gains more capacitance in the near future this problem should be solved.

BMJ2K project was meant to be a platform for further development. The possible options of improvement are:

- remote control via Wi-Fi,
- installing cameras for terrain recon,
- distance sensor for detecting obstacles,
- pressure sensors at legs tip for passing through obstacles.

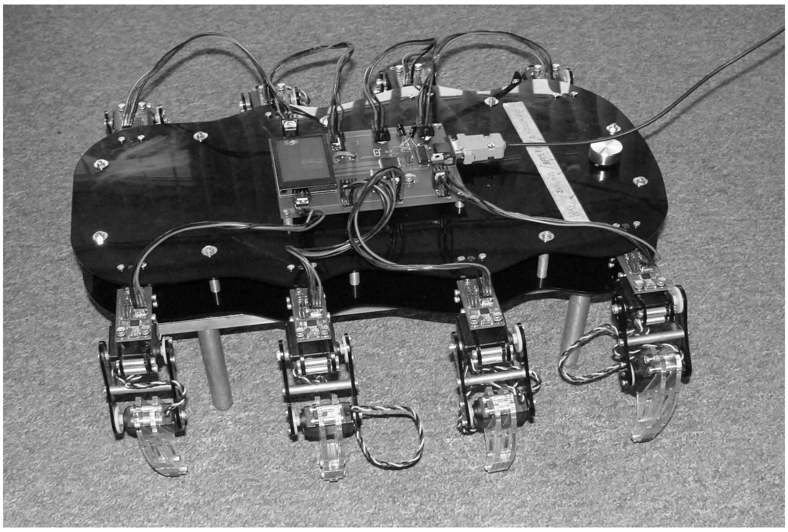

Fig. 10. Built robot

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