Walking Robot Workshop

step gait kinematics motion

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What is written in the heading?

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... today, we are about to create a »hello world« alà robotics.

Today's Workshop

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Workshop Goals

- Make robots walk with own program.
- Describe the walk mathematically.
- Get advanced insight into robotics.
- See, that STEM is worth learning.

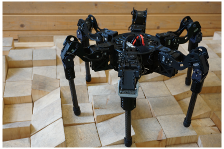
... A to vše za pouhé 4 hodiny.

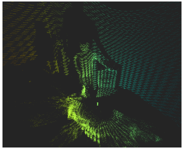
Rules

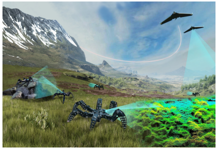
- Investigate, invent, try out!
- Cooperate as you want!
- No abrupt movements with the robots.
- Work in `Plocha/roboty/<today>`.

Martin Zoula (✉) | Filip Kučera (✉)

`comrob.fel.cvut.cz`







FACULTY OF ELECTRICAL ENGINEERING CTU IN PRAGUE

AI CENTER FEE CTU

 Picture sources: `https://comrob.fel.cvut.cz/`, `https://www.aic.fel.cvut.cz/`

Slides are Online

https://gitlab.fel.cvut.cz/crl/public/courses/kracejici_roboty_ntk

Our Robots – Today's »Robota«

Hexapod ∼ ant

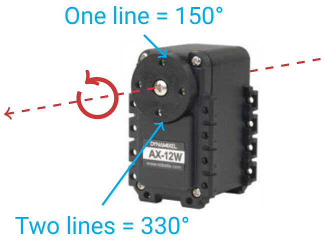
- 6 legs, 3 joints per leg.
- 24 degrees of freedom altogether.
- Statically stable walk is possible.
- Different gaits - 3pod, 4ped, 5pod...

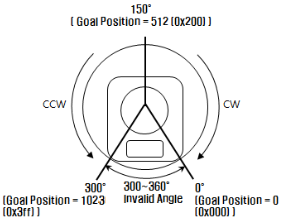
Humanoid ∼ biped ∼ člověk

- 6 joints per leg, 3 joints per arm.
- 18 *controllable* degrees of freedom.
- Walk not stable!

 Pictures source: `https://emanual.robotis.com/docs/en/edu/bioloid/premium/`

Servomotor





Robotis Dynamixel AX-12W

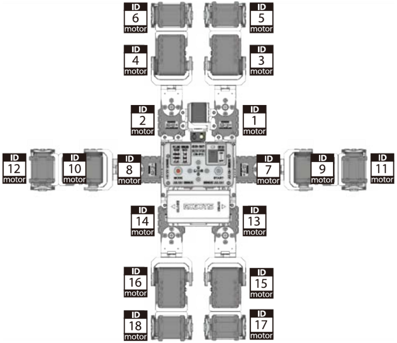
- DC gear electromotor with position control.
  (Beware! Shock may damage the gearbox!)
- Position feedback by potentiometer.
  (Dead angle! Rotor can not stop upside down.)
- Commanded from control unit by digital protocol.
  (Each servo was assigned unique ID number!)
- We can read or set different servo properties.
  (Speed, maximum torque, angle, temperature, stall...)
- Reference manual here.

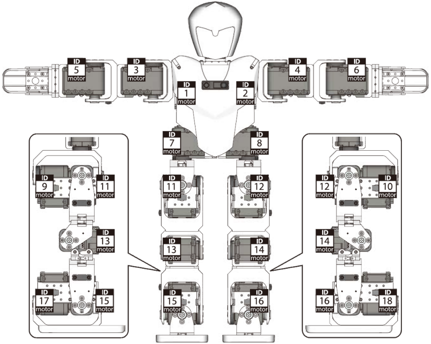
 Picture and schematic source: `https://emanual.robotis.com/docs/en/dxl/ax/ax-12w/`

Task: Get to Know Your Robot

- Move the robot by hand.
- See how the robot moves.
- »RoboPlus Manager« displays angles.

- Draw a robot schematics.
- Mark angle reckoning orientation.
- Where is fixed the stator/rotor?





Pictures source: `https://emanual.robotis.com/docs/en/edu/bioloid/premium/`

Task: First Steps

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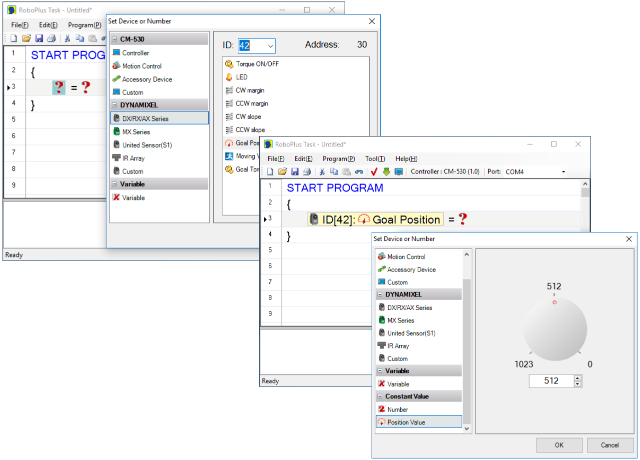
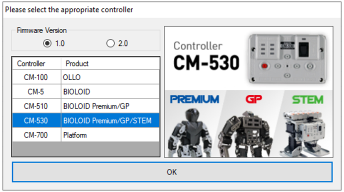
1. Launch »RoboPlus« → »Task«.
2. New file, choose controller type.
3. Spacebar to insert empty line.
4. Double-click to insert code.
5. Set some/all servos to 0°.
6. Upload over correct COM port.





Only one app can be connected to the robot at a time.

 Program examples from RoboPlus Task. (`https://robotis.co.uk/software/roboplus-1-0.html`)

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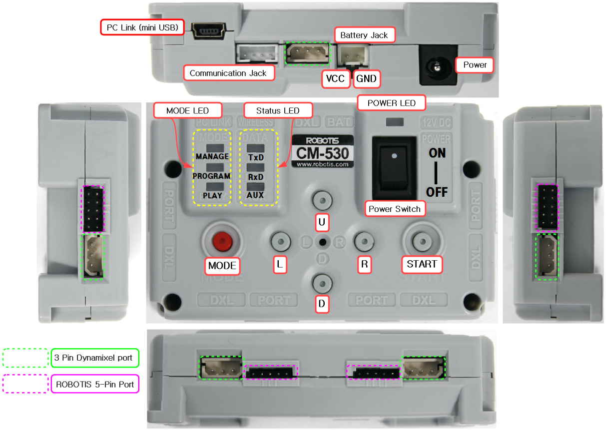


STM32F103RE ARM MCU, 72 MHz, 512 kB

- Stores and executes programs contrilling the servos.
- Programmed in PC graphical interface, flashed over USB.
- Online servo inspection.
- Red button to choose »play« mode, then press »start«.
- Kill program with red button. Power switch in emergency.

 Picture source: `https://emanual.robotis.com/docs/en/parts/controller/cm-530/`

[Hexapod] Task: Waving the Leg

!!! Preset movement speed may be high!

1. Set all servos movement speed to 50.
2. Set all servos angle to zero.
   (Hence define robot's initial pose.)
3. Make a leg to move there & back again.

! ! Servo is a »worker«, just follows orders. If the »boss« (CM-530) makes two set-angle commands without waiting, only the latter effectively happens.

4. Use `WAIT WHILE` with Is Moving.

[CM-530]-ukol-kyvani-hexa-2

```
START PROGRAM
{
    // Zapnutí výkonu serv
    ID[All]: Torque ON/OFF = TRUE
    // Nastavení rychlosti serv.
    ID[All]: Moving Velocity = 50
    // Nastavení základní pozice robotu.
    ID[All]: Goal Position = 512
    Timer = 2.048sec
    WAIT WHILE ( Timer > 0.000sec )
    // Kývání pravým středním femurem
    LOOP FOR ( i = 0 ~ 6 )
    {
        ID[9]: Goal Position = 860
        WAIT WHILE ( ID[9]: Is Moving == TRUE )
        ID[9]: Goal Position = 512
        WAIT WHILE ( ID[9]: Is Moving == TRUE )
    }
    // Povolení serv - zabráníme přehřívání
    ID[All]: Torque ON/OFF = FALSE
}
```

 Program examples from RoboPlus Task. (`https://robotis.co.uk/software/roboplus-1-0.html`)

[Humanoid] Úkol: Kývání nohou

- Humanoidova noha je složitá. Prosté vynulování serv by vzpříčilo díly robotu.

1. Vyvolejte »pohyb č. 25«, nechť toto je naše počáteční pozice.

- Pohyb má definované i rychlosti. Poslední rychlost zůstane nastavena.

2. Nastavte všem servům rychlost 50.
3. Hýbejte servomotorem sem a tam.
4. Kontrola dokončení pohybu viz sl. 11.

- Serva se mohou při zátěži přehřát.

5. Vypínejte mezi programy »torque«.

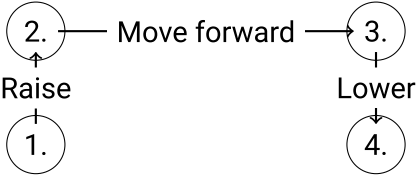
[CM-530]-ukol-kyvani-humanoid

```
START PROGRAM
{
    // Inicializace - počáteční poloha humanoida
    Motion Index Number = 25
    WAIT WHILE ( Motion Status == TRUE )
    // Nastavení rychlosti pohybu
    ID[All]: Moving Velocity = 50
    // Kývání kyčlí
    LOOP FOR ( i = 0 ~ 5 )
    {
        ID[8]: Goal Position = 700
        WAIT WHILE ( ID[8]: Is Moving == TRUE )
        ID[8]: Goal Position = 512
        WAIT WHILE ( ID[8]: Is Moving == TRUE )
    }
    // Povolení motorů
    ID[1]: Torque ON/OFF = FALSE
}
```

Ukázka zdrojového kódu vytvořena v RoboPlus Task. (https://robotis.co.uk/software/roboplus-1-0.html)

Task: Program One Leg Step

Hexapod

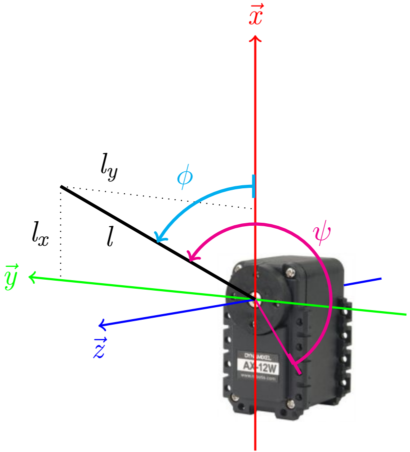


Humanoid

- Mind the mass! Always catch the robot!
- »Motion Index 25« lowers the torso.
- Move only the ankle and hip.

- You need to identify which particular angles to set!
- Divide your work. (Each identify one leg...) Mind the servo orientation!
- There are different step trajectories. (Triangle, square, ellilpse, adaptive, ...)
- Do not forget to wait before each intermediate move finishes.

Servo Described by Math



- Angle ψ: Defined by manufacturer.
  - (We set/read this when programming.)
- Angle ϕ: Kinematically meaningful.
  - Positive angle along z-axis.
  - Zero-angle aligned with x-asix.
  - (Right-hand rule.)

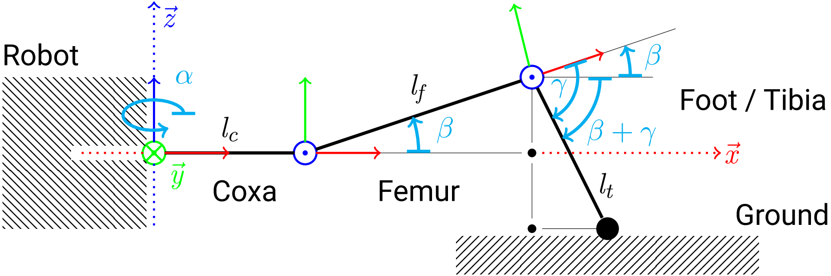
$$l_x = l\cos(\phi)$$

$$l_y = l\sin(\phi)$$

$$\phi = \psi - 150°$$

 Servomotor picture source: `https://emanual.robotis.com/docs/en/dxl/ax/ax-12w/`

Leg, a.k.a. kinematic chain



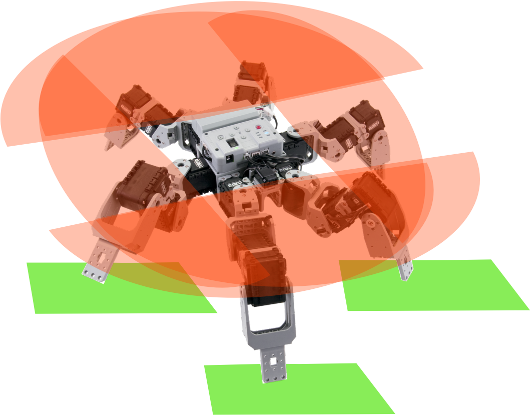
Direct kinematic task: Servomotor angles $\rightarrow$ foot coordinates.

$$x_{chod.}(\alpha, \beta, \gamma) = \cos(\alpha)\left[l_c + l_f\cos(\beta) + l_t\cos(\beta+\gamma)\right]$$

$$y_{chod.}(\alpha, \beta, \gamma) = \sin(\alpha)\left[l_c + l_f\cos(\beta) + l_t\cos(\beta+\gamma)\right]$$

$$z_{chod.}(\alpha, \beta, \gamma) = l_f\sin(\beta) + l_t\sin(\beta+\gamma)$$

Motion Limitations



- Robot has many degrees of freedom. Can it use them fully?
- Joint angles are limited by design.
- Legs operation spaces intersect.
- Walk needs to take this into account!
- Also, environment might get in the way. (Terrain, obstacles, people, machines...)

 Hexapod image source: `https://emanual.robotis.com/docs/en/edu/bioloid/premium/`

Grand Task: Walk

1. Wrap a code for a single step into »function«.
2. Make such function for each leg. Double-check the IDs.
3. Servos may be oriented differently at each leg. Check it.
4. [Hexapod] Make a function to move all Coxas backwards, moving the robot forth.
5. Call the functions in meaningful order.

BEWARE!

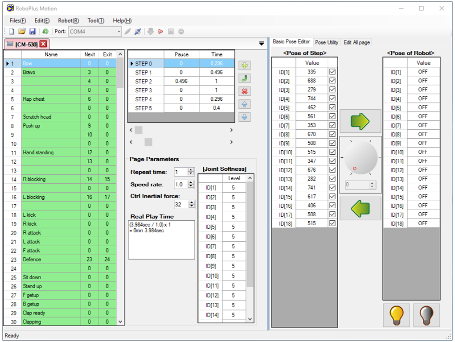
- Pay attention to leg collisions.
- Adjust the walk parameters to avoid collisions.

Preprogrammed Motions

- Robot has several preprogrammed motions always ready.
- Use »RoboPlus Motion« to play them back.
- You can launch the motions also programmaticaly.

[CM-530]-stub-motion

```
1:  START PROGRAM
2:  {
3:          // Začne vykonávat přednastavený cvik.
4:          Motion Index Number  = 42
5:          // Program je třeba zastavit dokud není cvik dokončen.
6:          WAIT WHILE  ( Motion Status  ==  TRUE  )
7:  }
```



 Program examples from RoboPlus Motion and Task. (https://robotis.co.uk/software/roboplus-1-0.html)

Sensors

Robots are furnished with distance sensors and microphone to detect clapping.

[CM-530]-stub-distance

```
START PROGRAM
{
    // Vyčtení hodnoty do proměnné
    přečteno  = PORT[1]:IR Sensor
    // Použití hodnoty přímo v programu
    IF ( PORT[1]:IR Sensor  <=  100  )
    {
        // ...
    }

    // Senzor tlesknutí - čekám na jeden tlesk.
    Result of Sound Counter  = 0
    WAIT WHILE  ( Result of Sound Counter  <  1  )
    // Zahraji melodii.
    Buzzer Time  = Play Melody
    Buzzer index  = Melody2
    WAIT WHILE  ( Buzzer Time  >  0  )
}
```

 Pictures source: `https://emanual.robotis.com/docs/en/parts/all_sensors/`

Final Task: Make the Robots Dance

1. Robot waits until there is a clap.
2. Then, it executes some motion.
3. Then, waits for another clap.
4. Then, different motion is executed.
5. ... or anything you imagine.
6. Use sensors to avoid obstacles.
7. Accelerate the hexapod by »tripod gait«.