Formation Control of Multiple Robotic Fish

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Our Goal

How did the magician realize this?

Introduction

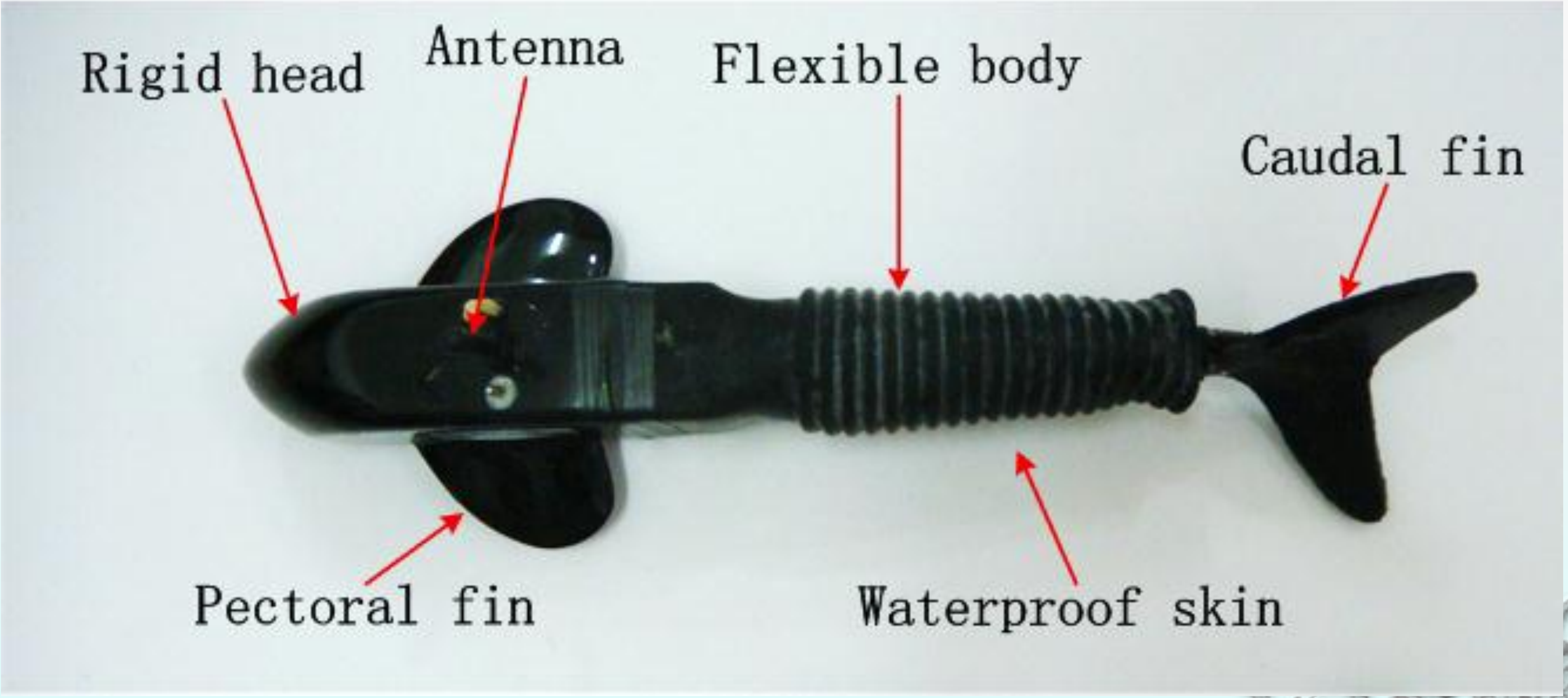
- Application Background
  - Ocean mapping and exploration
  - Water environment surveillance
  - Autonomous underwater weapon
- Multiple underwater robot coordination
  - Provide significant benefit

Introduction

- Formation Control
  - Basic problem of MRS
    - base of high level applications
  - Many results on wheeled robots/vehicles
    - Simulation & Physics
  - Few results on underwater robots
    - Simulation
  - No results on robotic fish
    - No Simulation

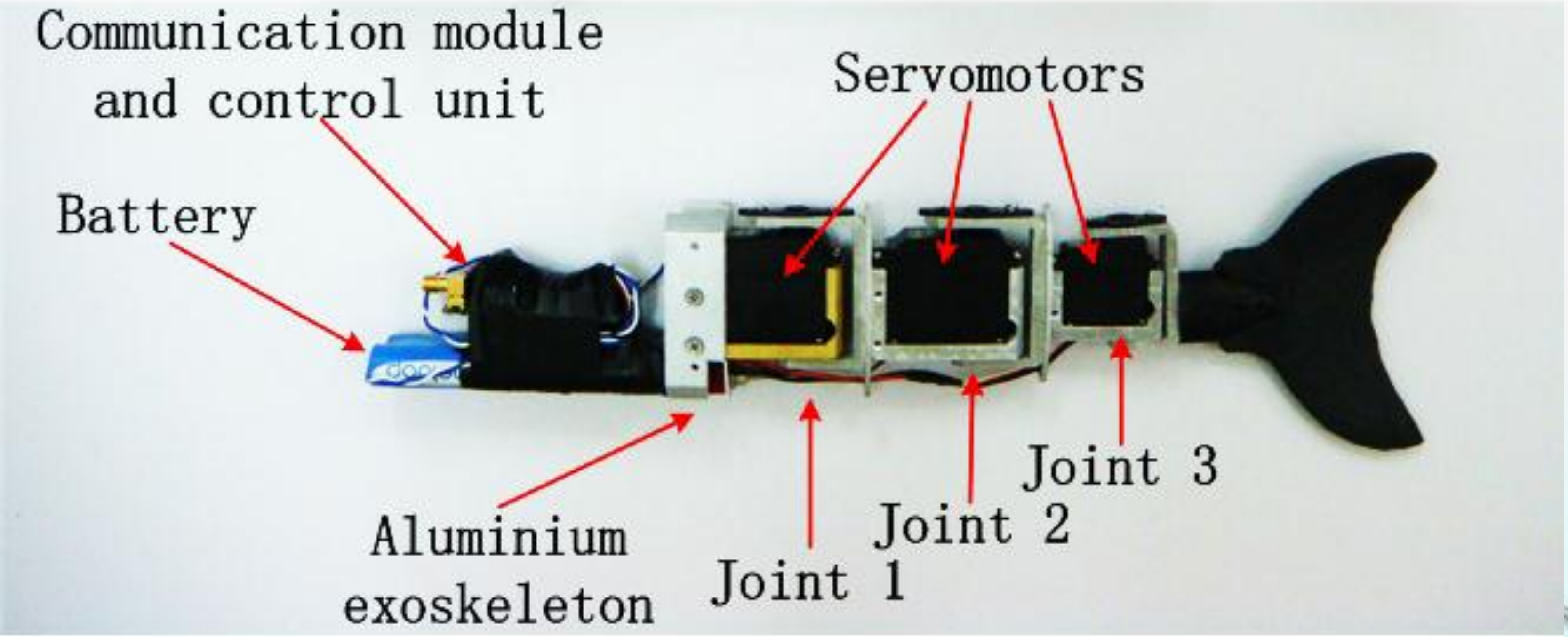
Introduction

- Robotic Fish



Introduction

- Robotic Fish



Robotic Fish Video

Problem Description

- We consider *N* robotic fish, $i=1,\ldots,N$, swimming in the same plane.
- For the *i*th robotic fish, we denote
  - (x_i, y_i): the position
  - θ_i : the direction angle
  - v_i : the line speed
  - ω_i : the angle speed

Formation Problem I

- [Static Formation] Given a set of desired positions $(x_{\mathrm{f}i},y_{\mathrm{f}i})$, $i=1,\ldots,N$, we have

i) $(x_1,y_1)-(x_{\mathrm{f}1},y_{\mathrm{f}1})=\ldots=(x_N,y_N)-(x_{\mathrm{f}N},y_{\mathrm{f}N})$

ii) $\theta_1=\ldots=\theta_N$

Formation Problem II

- [Moving Formation] Given a set of desired positions (x_{fi},y_{fi}), i=1,…,N, we have
  i) $(x_1,y_1)-(x_{f1},y_{f1})=\ldots=(x_N,y_N)-(x_{fN},y_{fN})$
  ii) $\theta_1=\ldots=\theta_N$
  iii) $v_1=\ldots=v_N$
  iv) $\omega_1=\ldots=\omega_N$

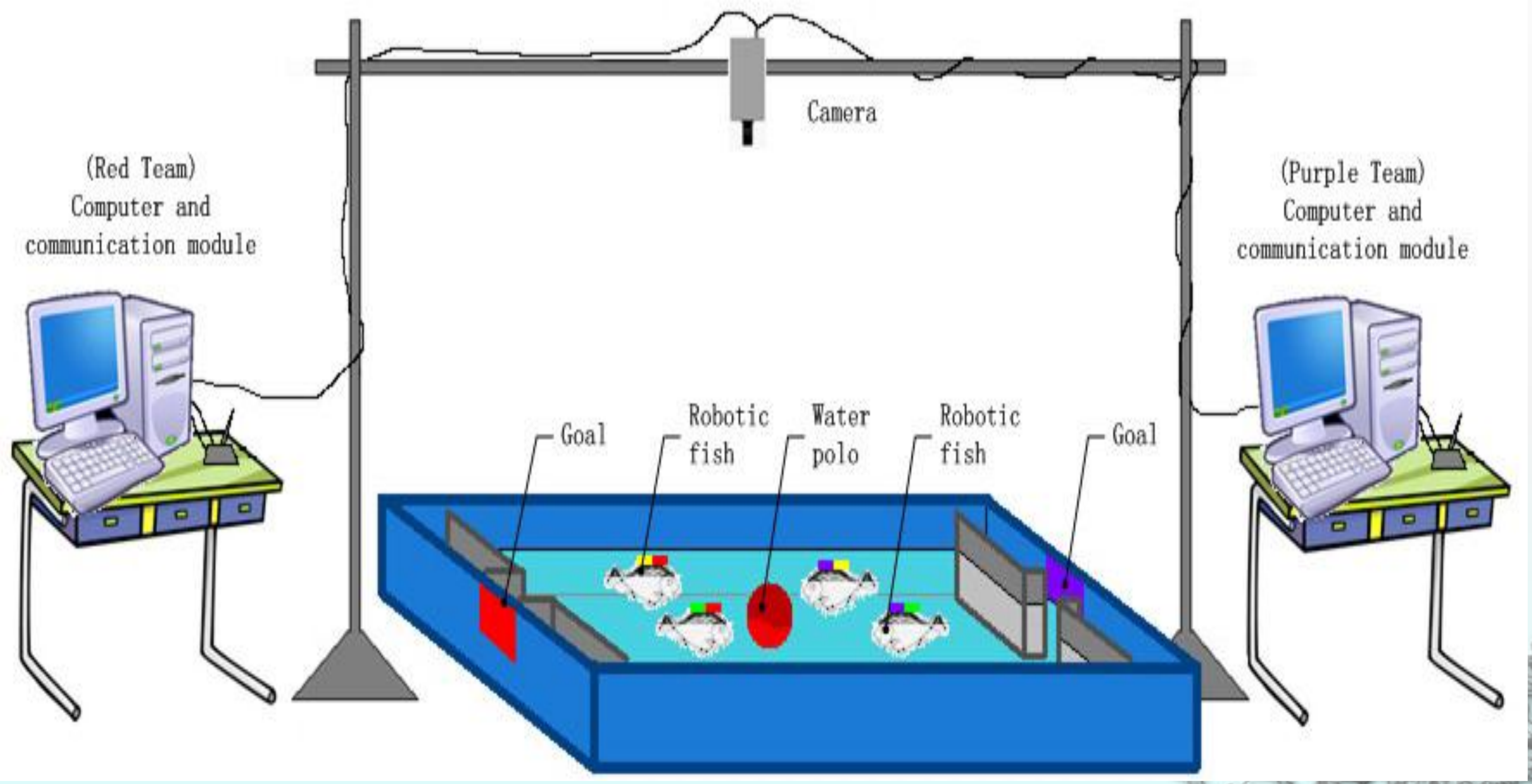
Control Law

- Line speed and angle speed are control inputs
  - v, ω
- Local information based
  - Communication graph
- Absolute coordinate information is used
  - Position (x,y)
  - Angle $\theta = \theta + 2k\pi$

Information Obtaining

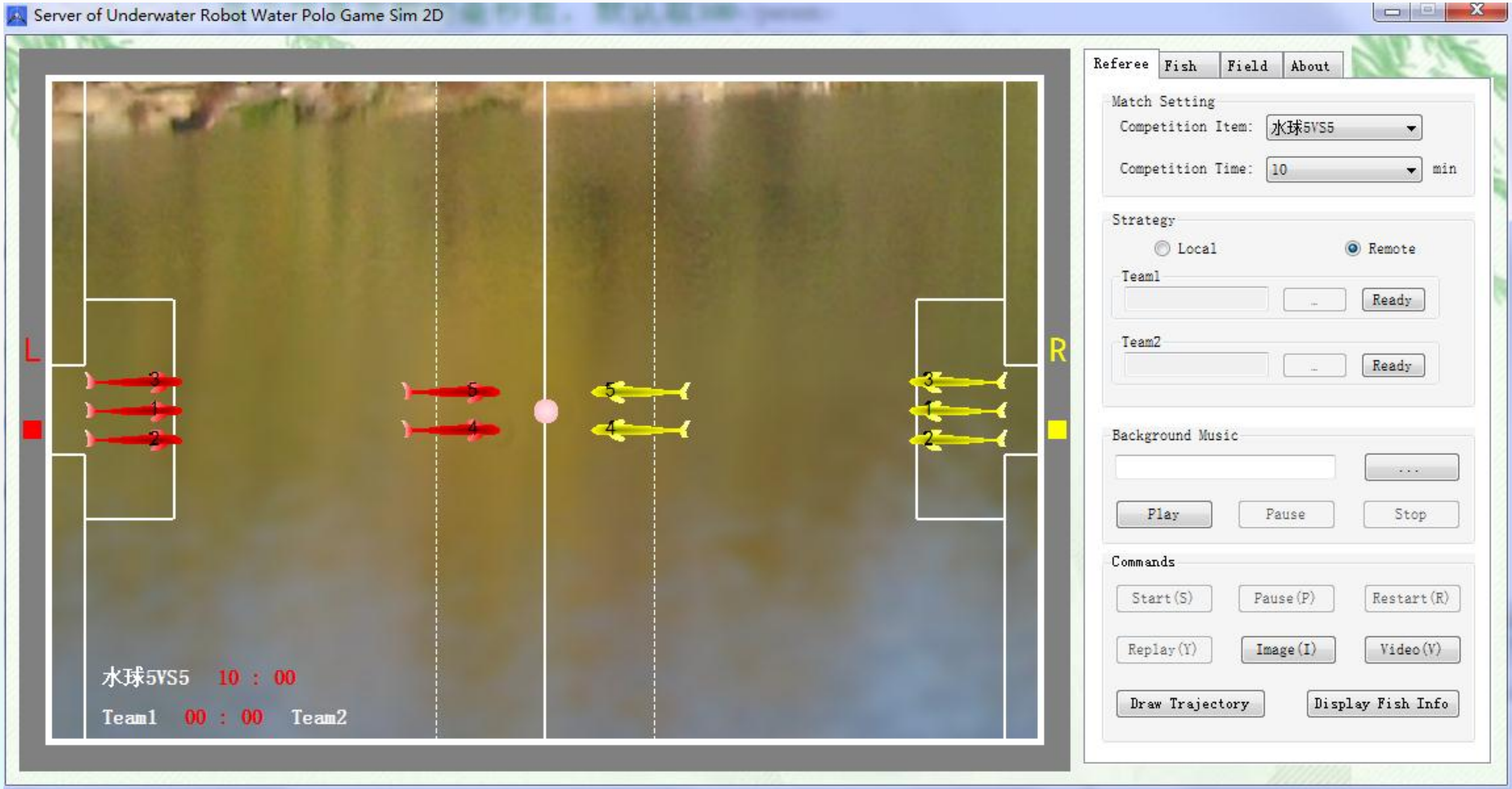
- No sensor on the robot
  - Focus On Motion Control
- Video From Global Camera
  - Global Obtaining
  - Local Using
- Getting Posture Knowledge From Image
  - Image Process
  - Real Time

2D Experiment Platform



Robotic Water Polo Video

2D Simulation Platform



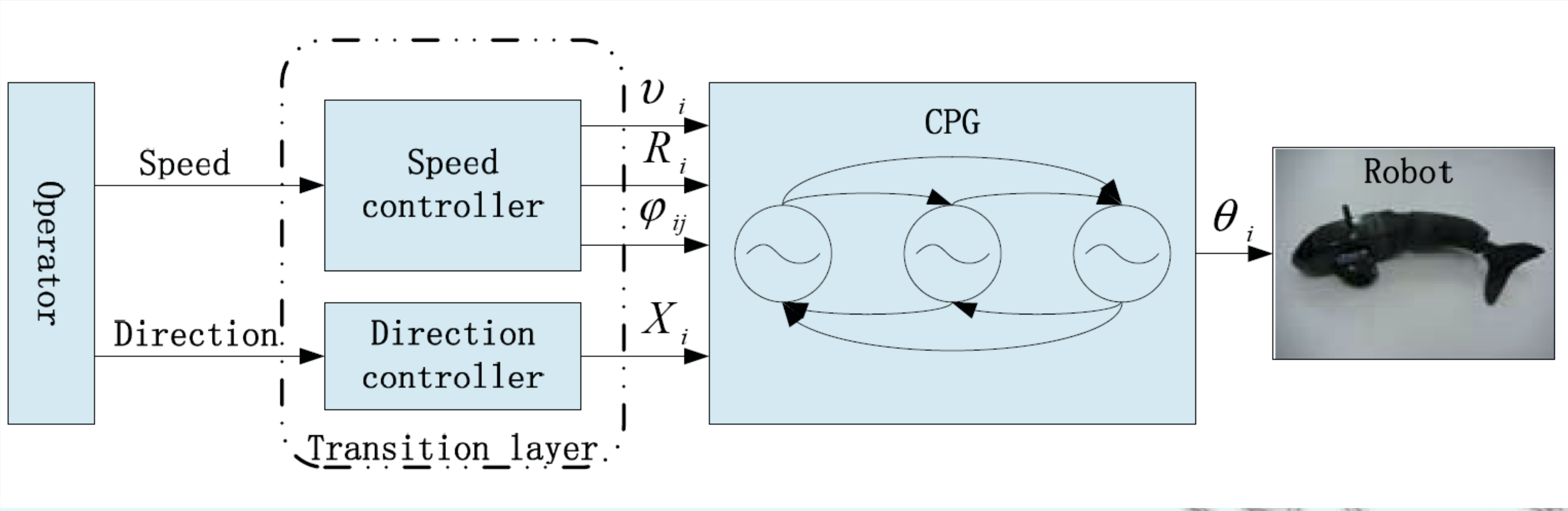
[Robotic Water Polo 2D-Sim Video]

Difficulties

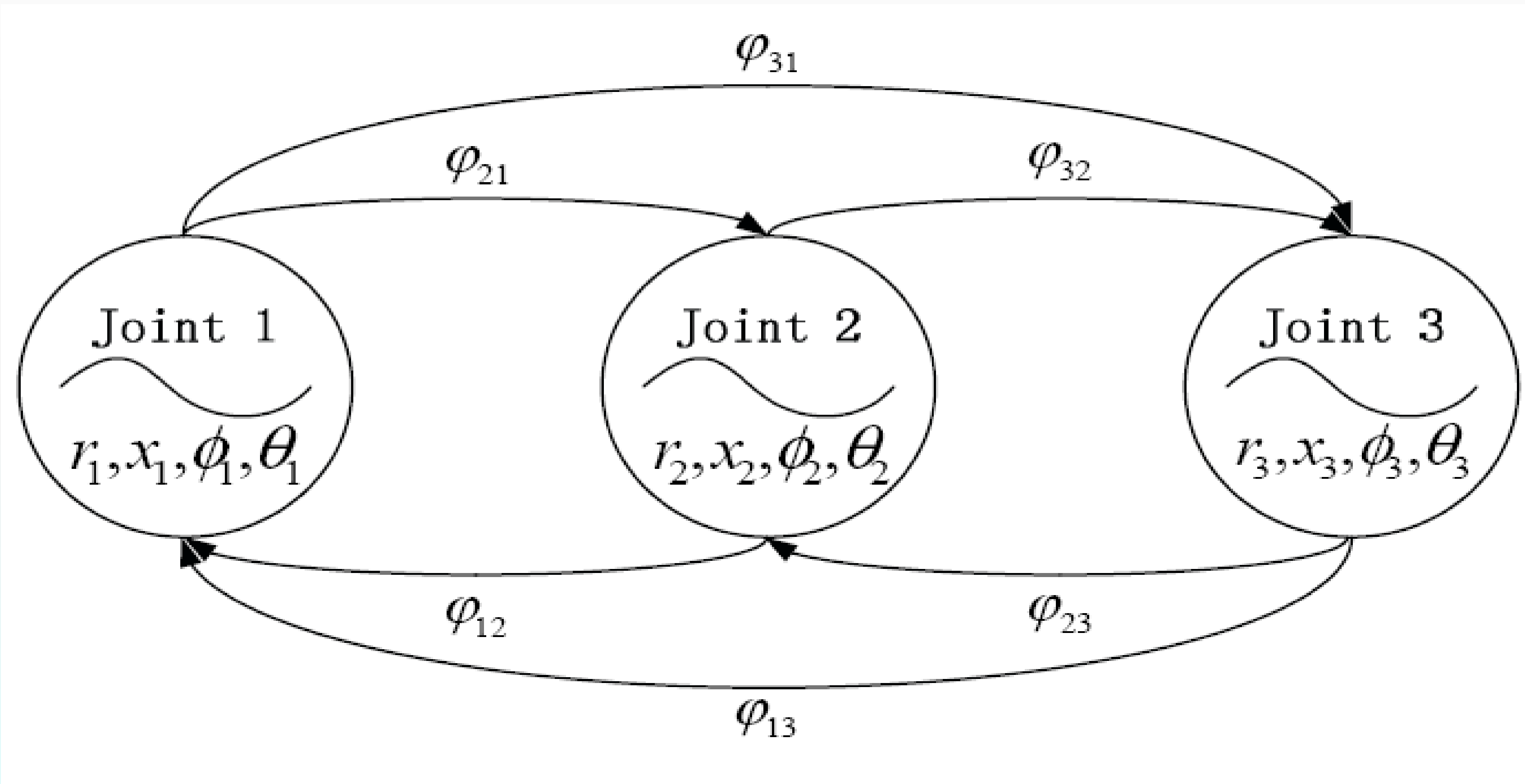
- Without dynamical equation
- Cannot move backward
- Cannot stop
- Float in the water always
- Coarse posture information

Locomotion Control of RF

- Central Patten Generator(CPG)-based



CPG Network


φ_{31}
φ_{21}
φ_{32}
Joint 1
$r_1, x_1, \phi_1, \theta_1$
Joint 2
$r_2, x_2, \phi_2, \theta_2$
Joint 3
$r_3, x_3, \phi_3, \theta_3$
φ_{12}
φ_{23}
φ_{13}

CPG Oscillator

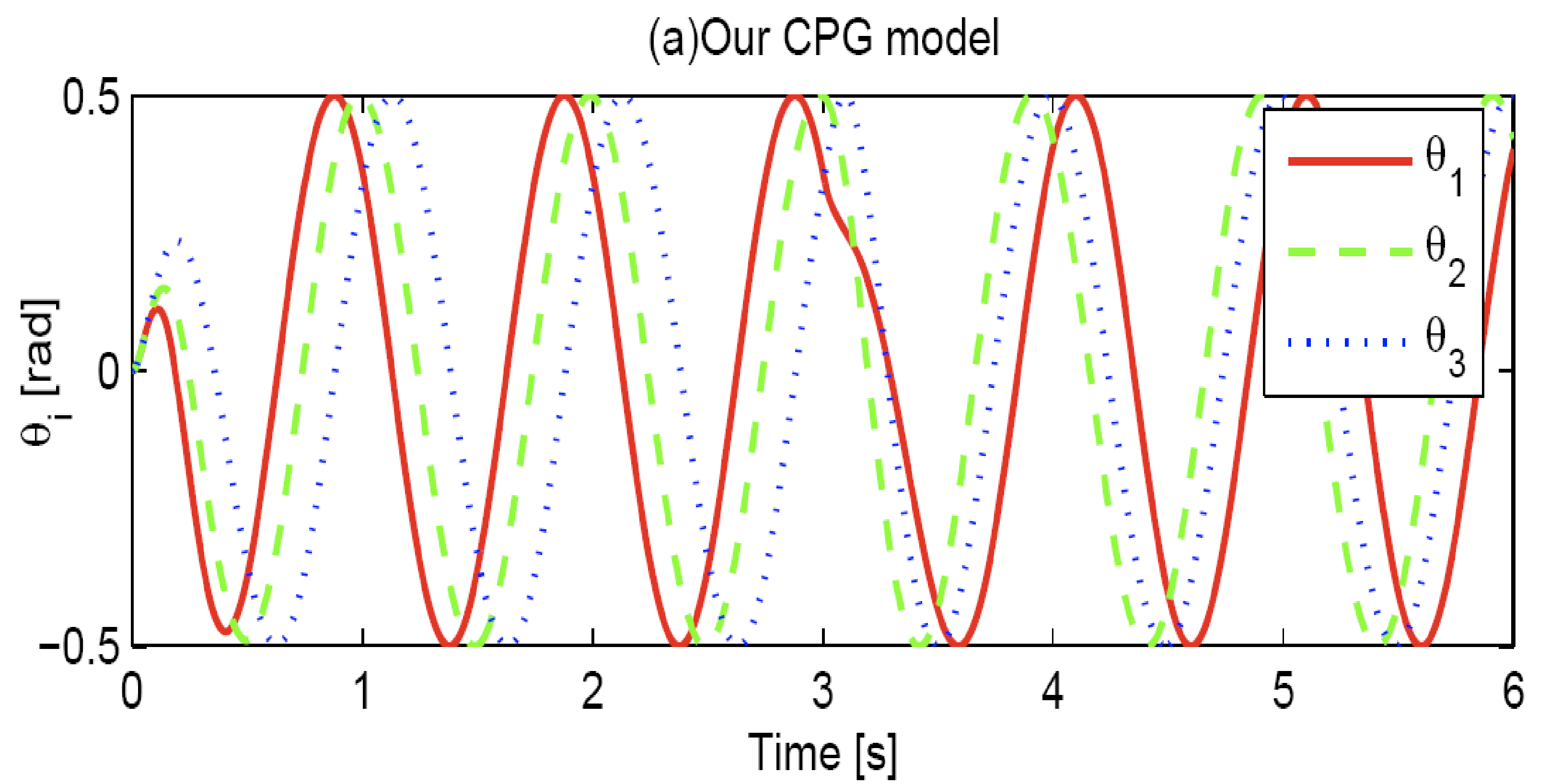
$$\ddot{r}_i(t) = \alpha_i[\alpha_i(R_i - r_i(t)) - 2\dot{r}_i(t)]$$

$$\ddot{x}_i(t) = \beta_i[\beta_i(X_i - x_i(t)) - 2\dot{x}_i(t)]$$

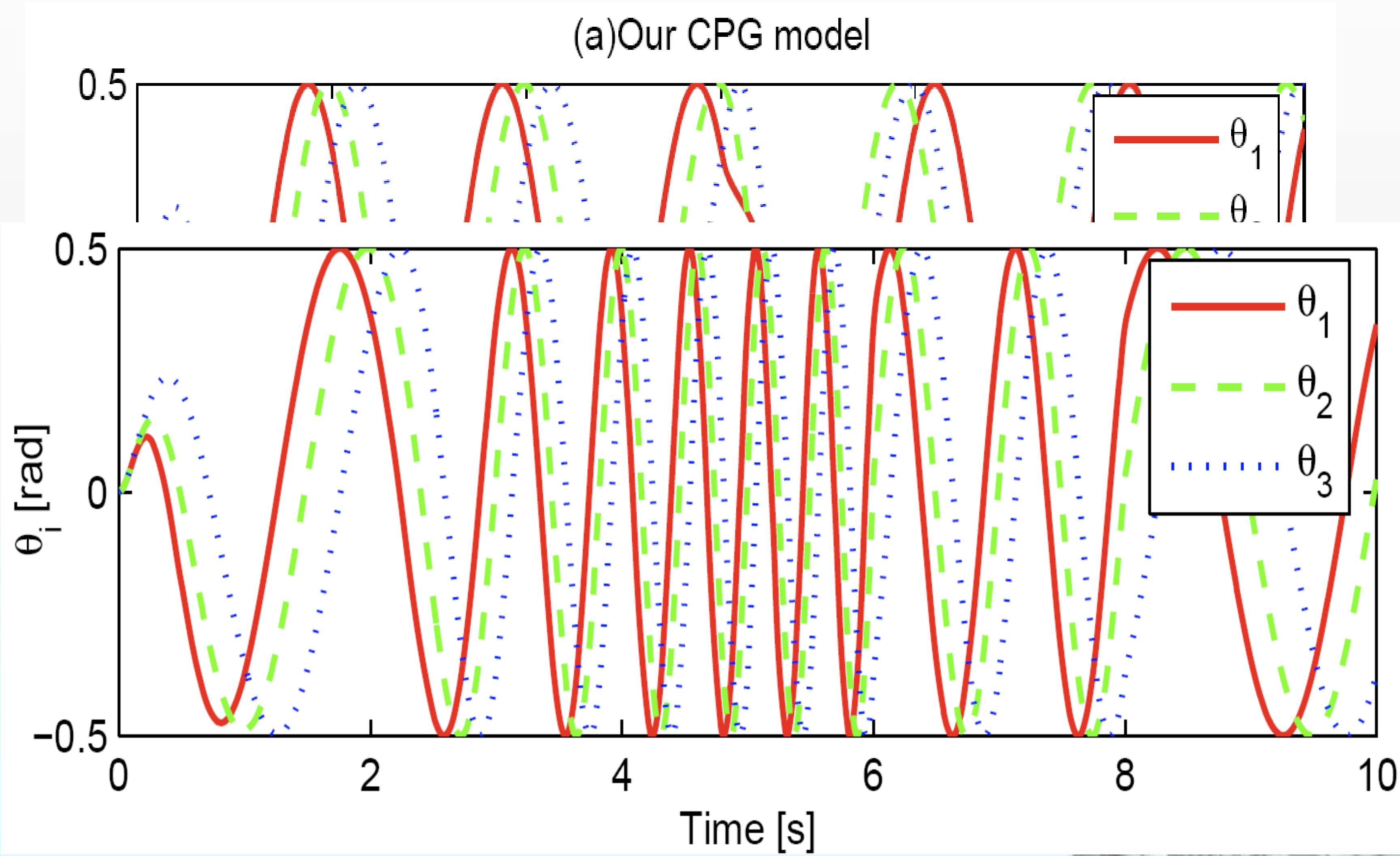
$$\ddot{\phi}_i(t) = \sum_{j=1, j\neq i}^{N} \mu_{ij} \left[\mu_{ij} \left(\phi_j(t) - \phi_i(t) - \varphi_{ij}\right) - 2\left(\dot{\phi}_i(t) - 2\pi\upsilon_i\right)\right]$$

$$\theta_i(t) = x_i(t) + r_i(t)\cos(\phi_i(t))$$

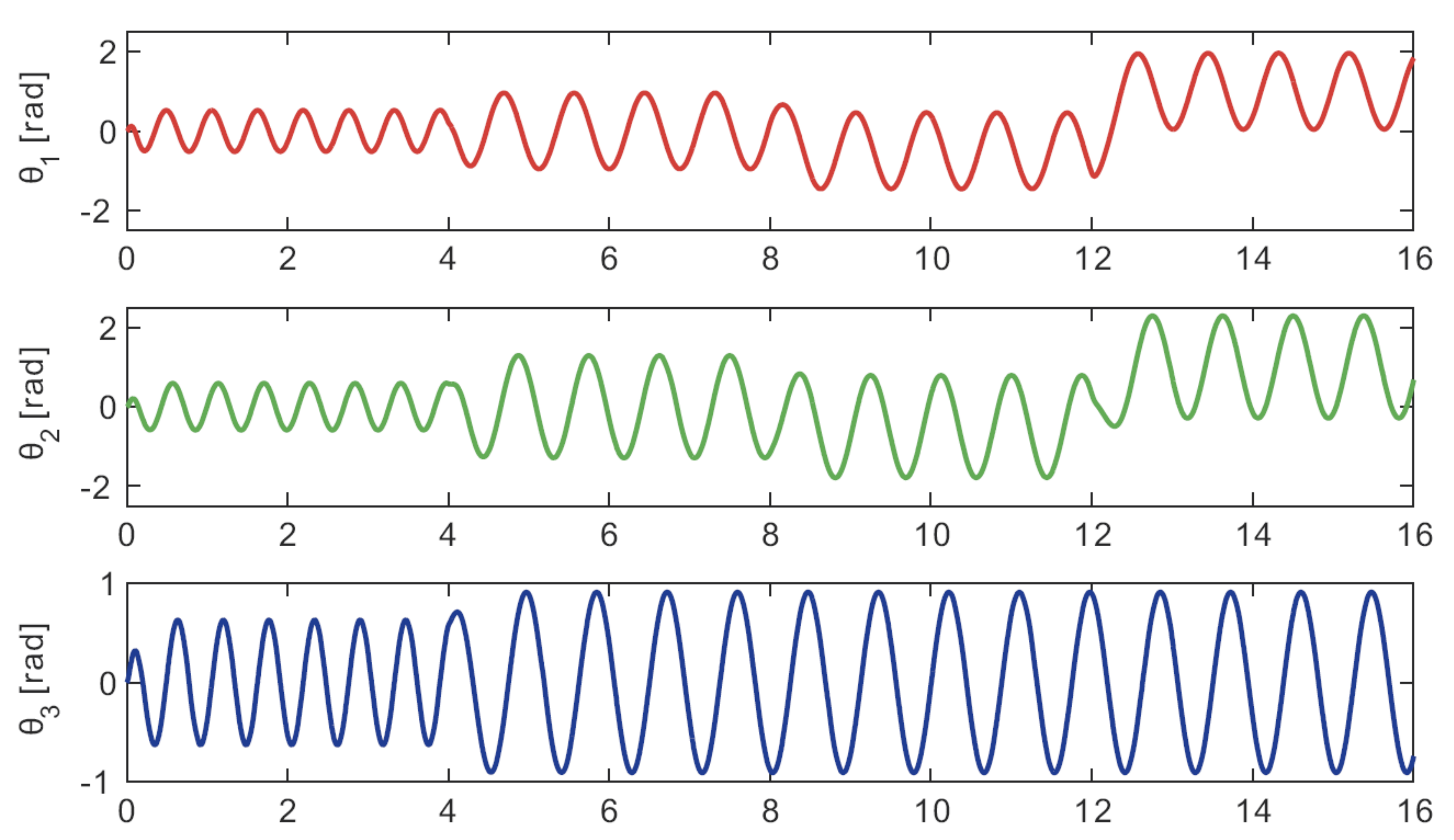
Outputs of CPG Network



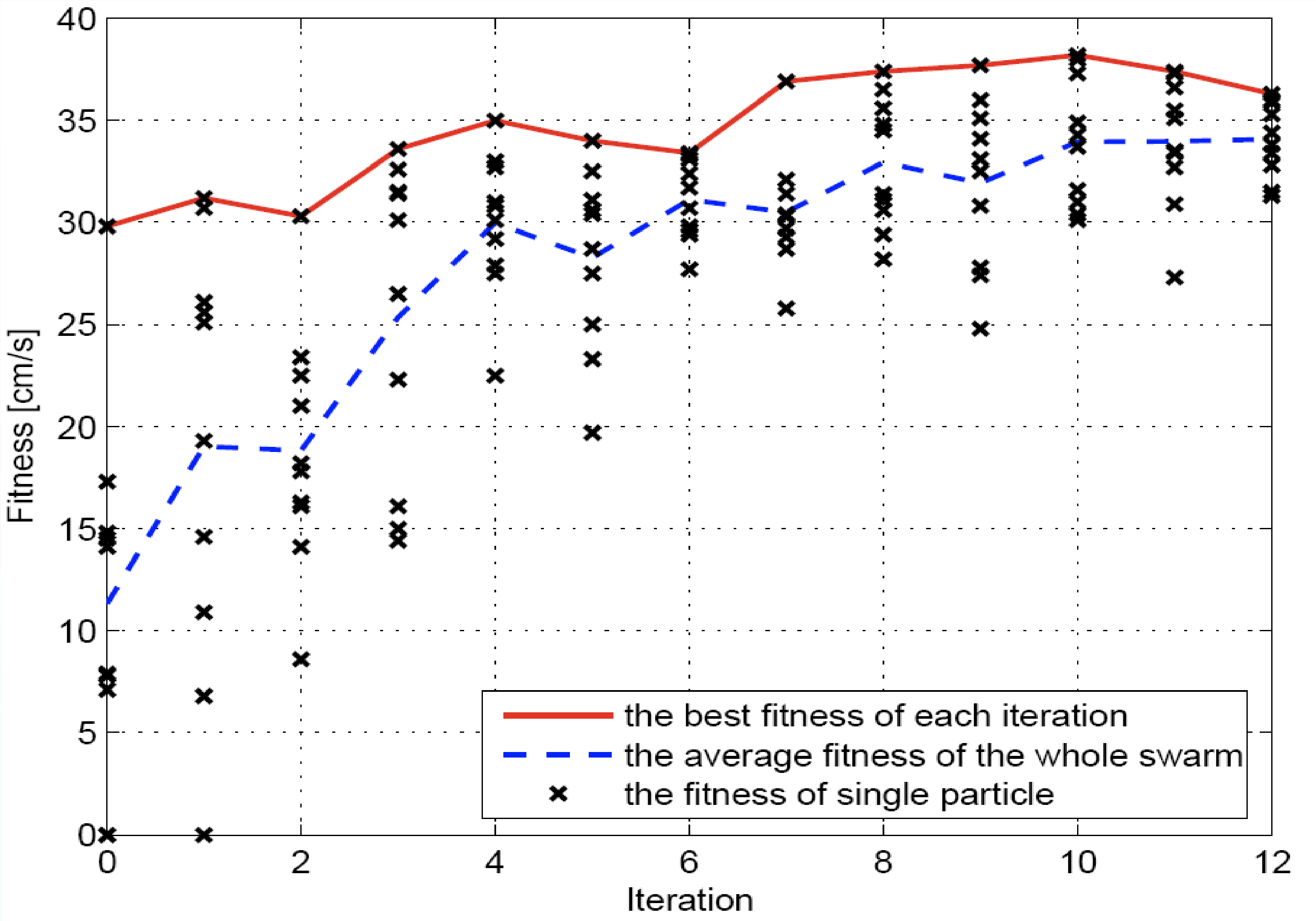
Outputs of CPG Network



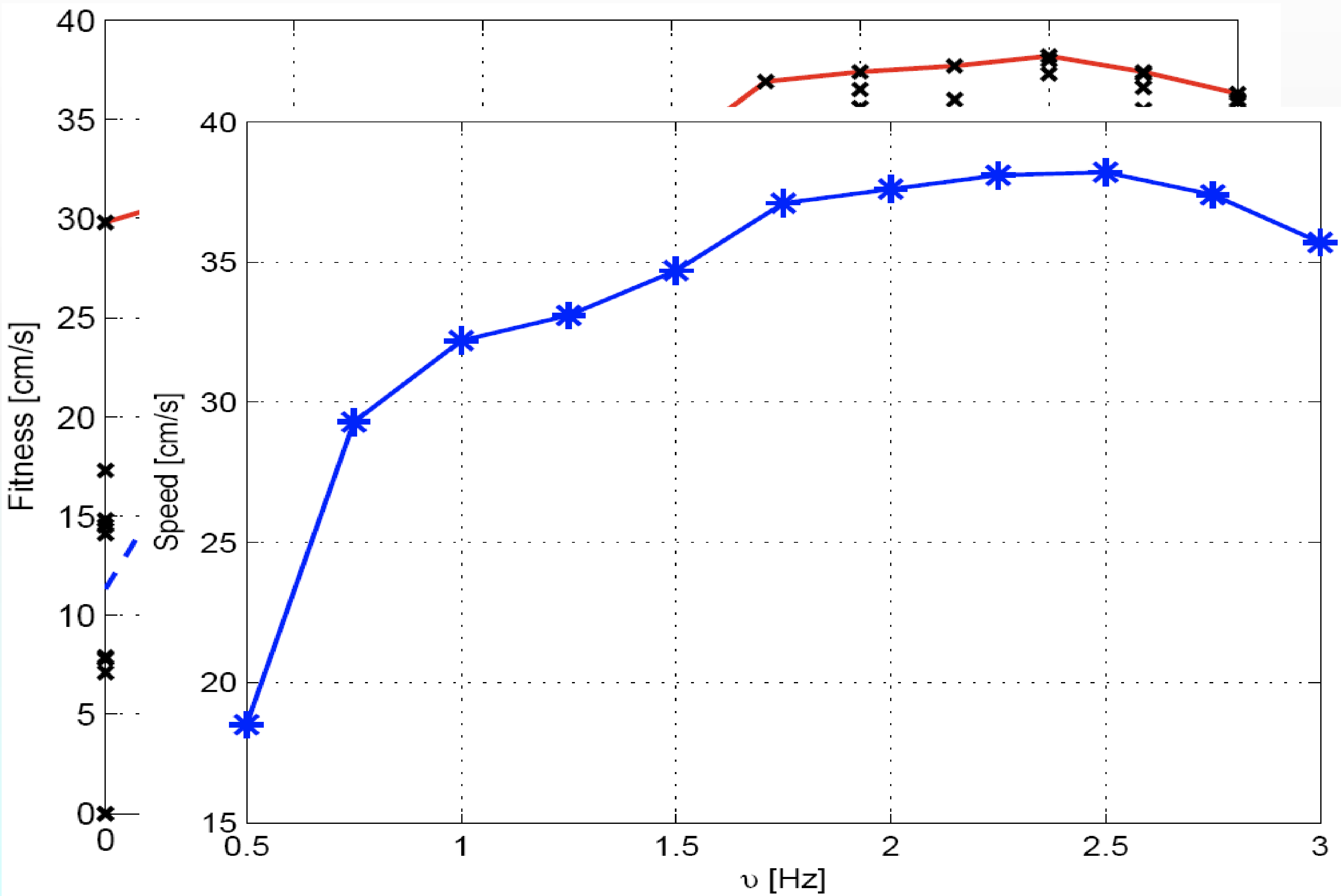
Outputs of CPG Network



Optimization via PSO



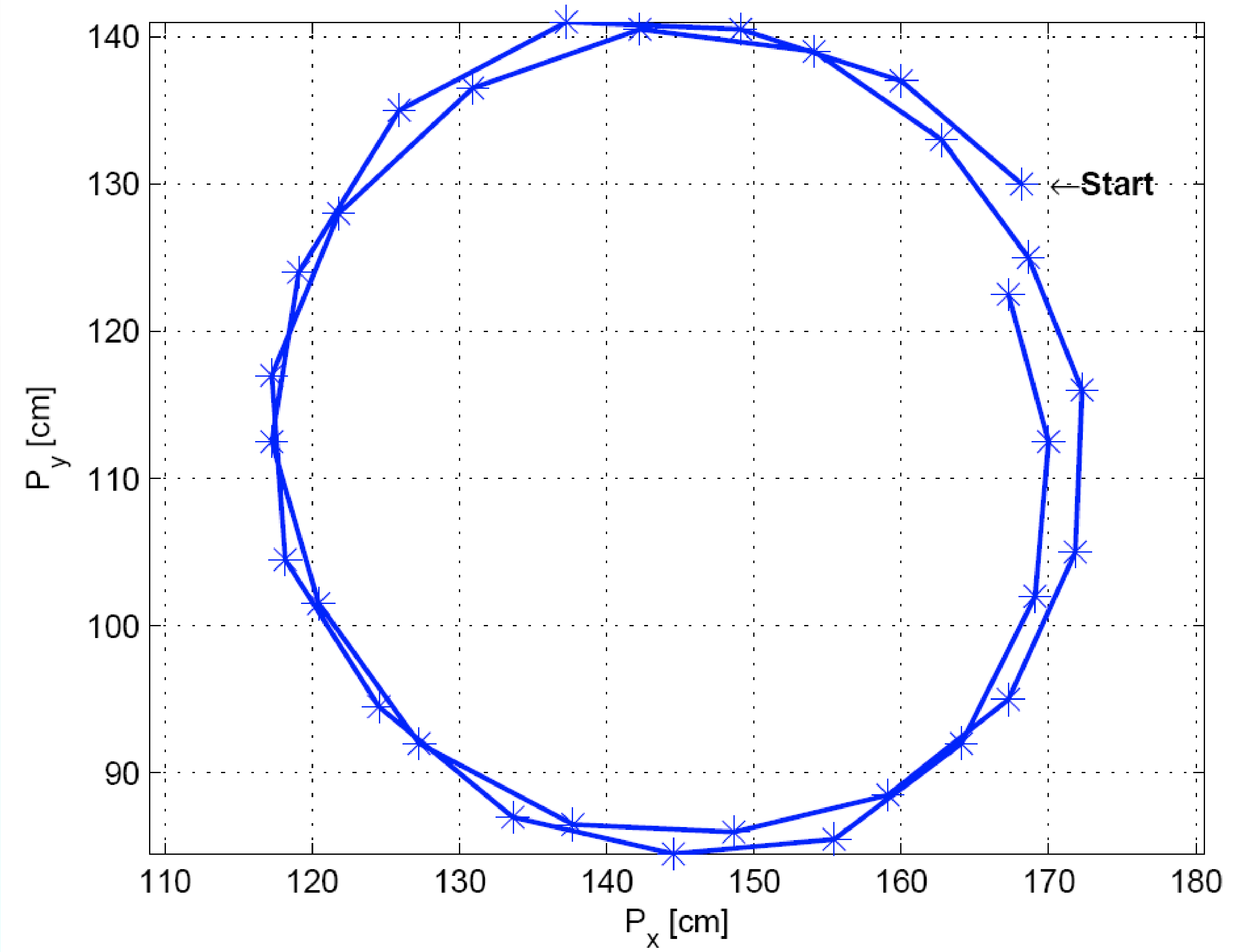
Optimization via PSO



Parameters Reducing

- From **18** parameters to **2** parameters
  - *Frequency*: linear speed adjusting
  - *Offset*: turning radius adjusting
    - $X>0$, turning left
    - $X<0$, turning right
    - $X=0$, swimming forward

X=-0.5*rad* and V=1.0*Hz*



Static Formation

- Based on Consensus control of first order MAS
  - $y = x - x_f$
  - $dy/dt = -Ly$

Formation Control 2D-Sim Video

Moving Formation

- Based on Consensus Control of second order MAS

Formation Control Video

Conclusion

- Just at the beginning
- Interesting but full of Challenge
- Any collaborations are welcome

Our Goal

Thank you for your attention！

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