FYT: GPS Robotic Water Analyzer

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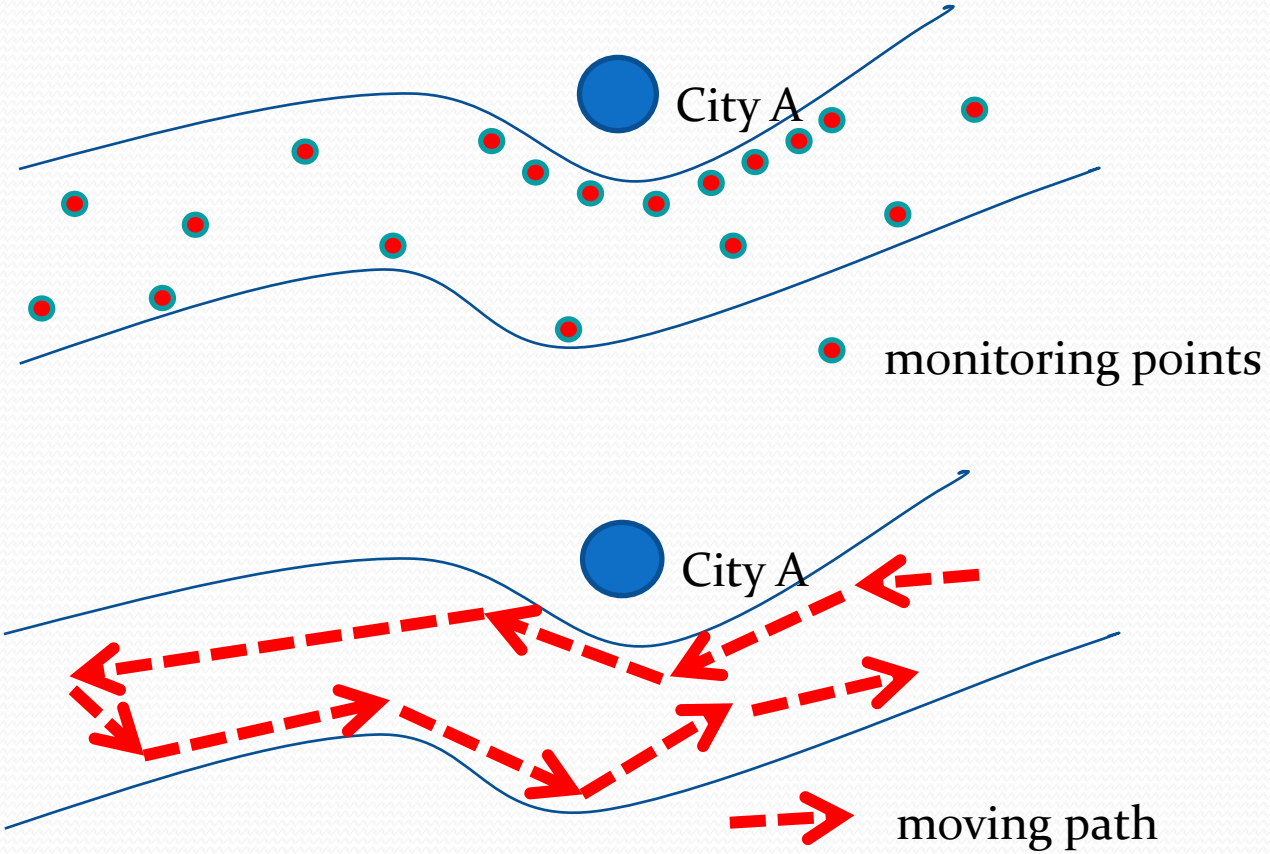
Outline

- Inspiration
- Workflow
- Hardware
- Mathematic Model
- Tests and Simulations
- Chemical Sensor Selection
- Conclusion

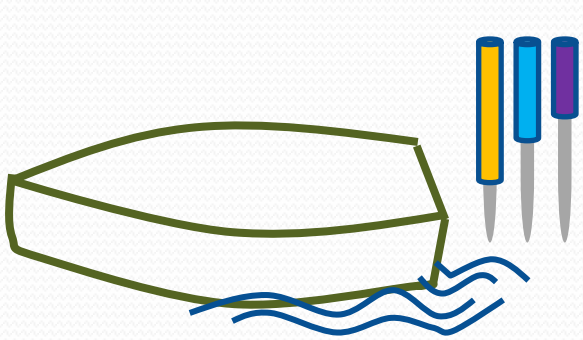
Inspiration



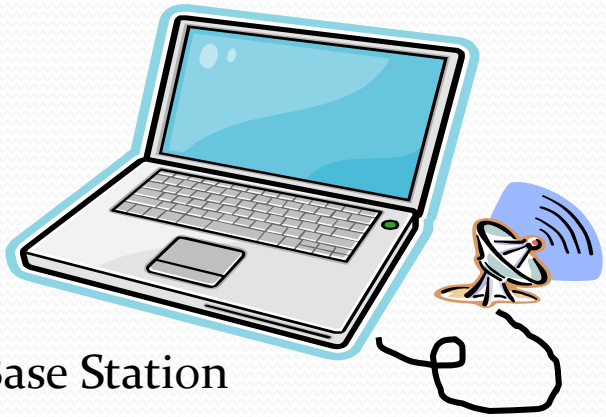
Inspiration

Movable Water Monitoring point

GPS Robotic Water Analyzer

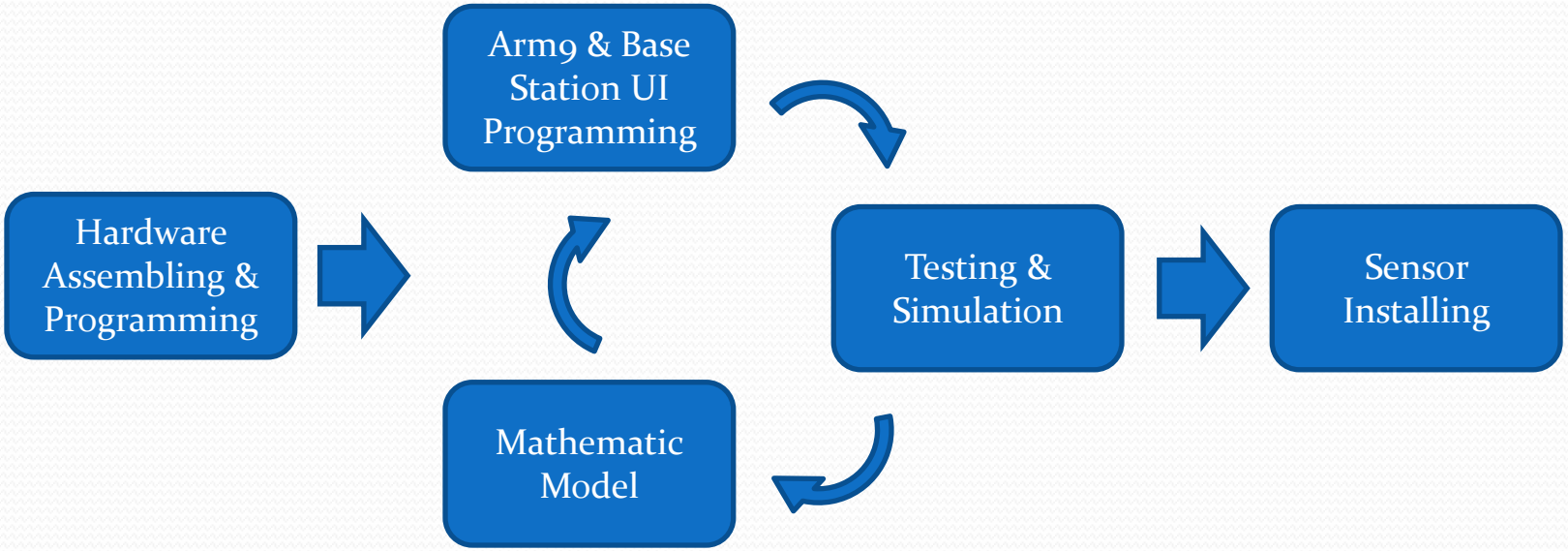


Robotic Boat Platform

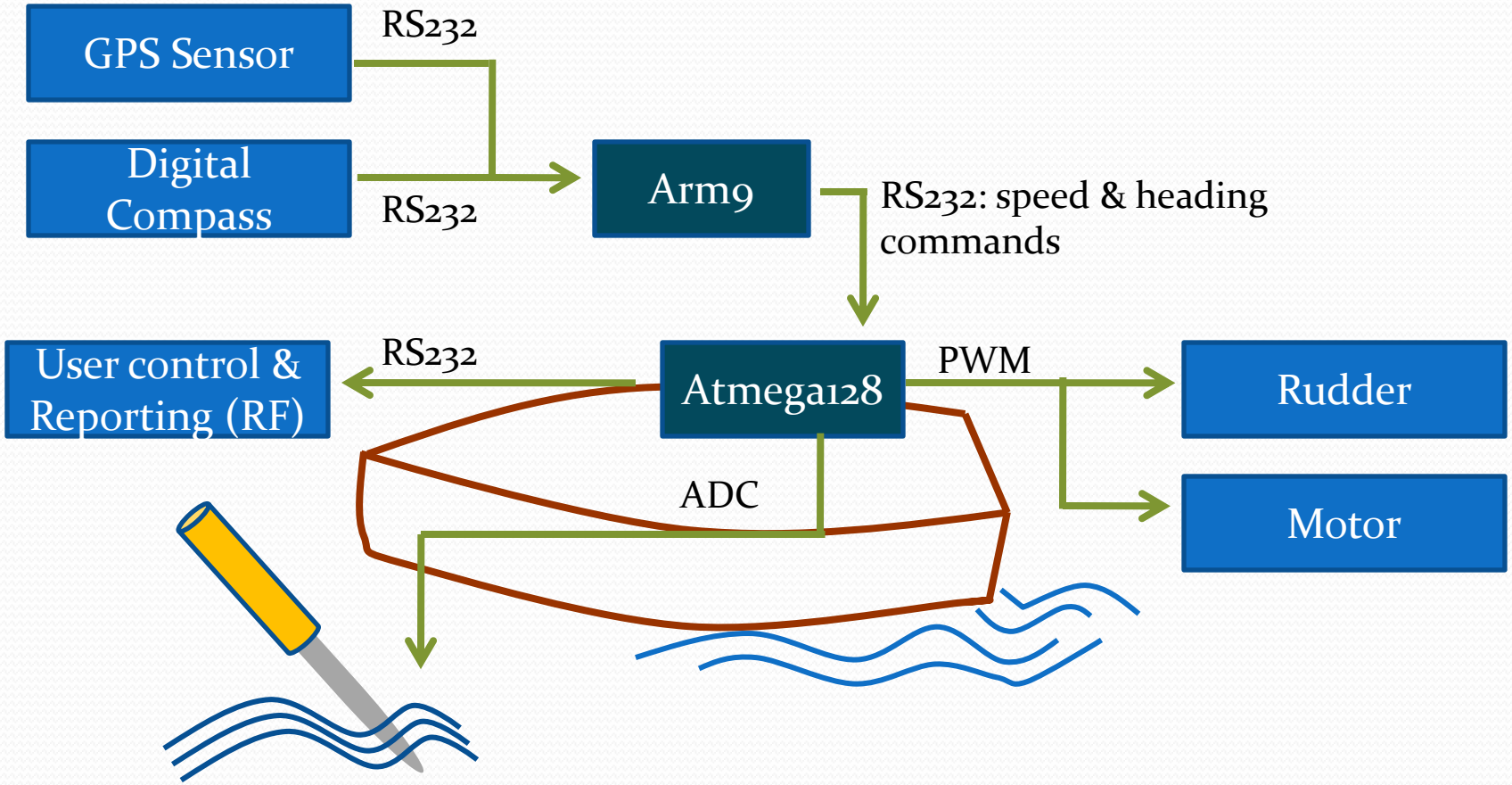


PC Base Station

Workflow


Arm9 & Base Station UI Programming
Hardware Assembling & Programming
Testing & Simulation
Sensor Installing
Mathematic Model

Hardware

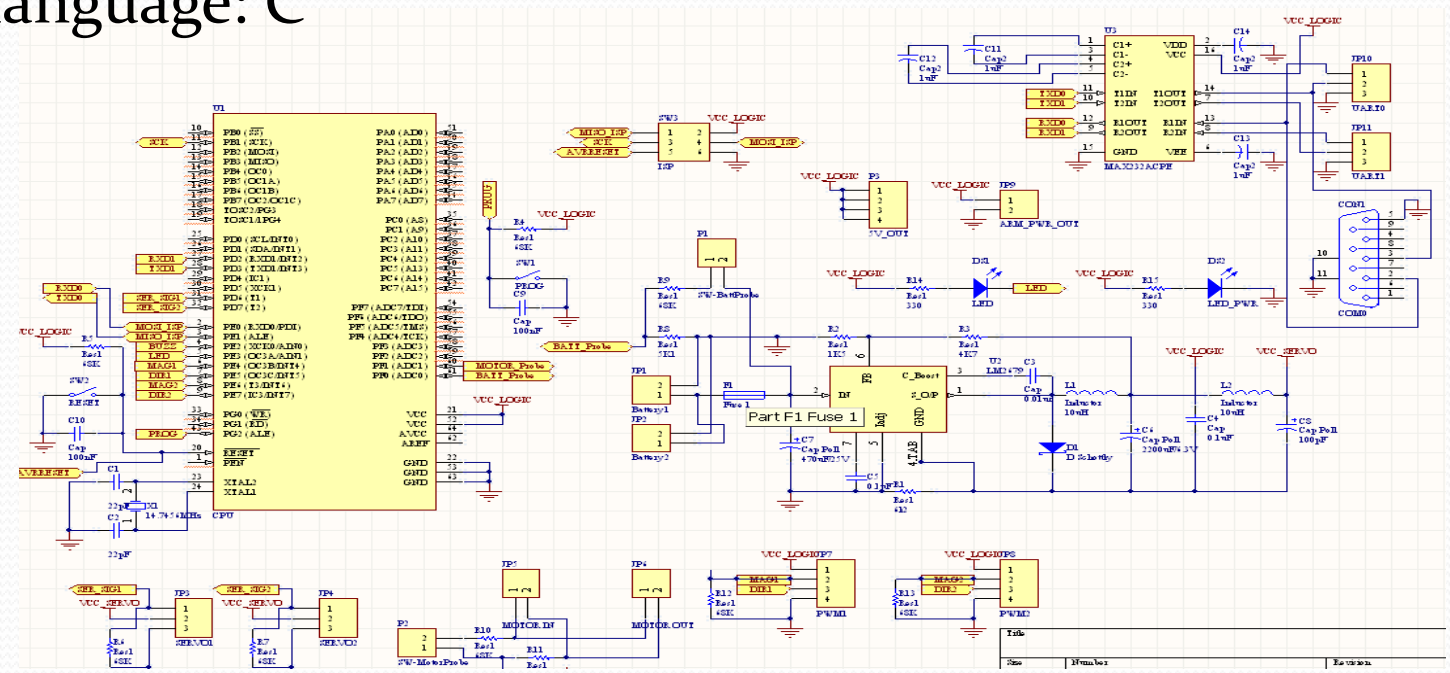

GPS Sensor
RS232
Digital Compass
RS232
Arm9
RS232: speed & heading commands
User control & Reporting (RF)
RS232
Atmega128
PWM
Rudder
ADC
Motor

Hardware

- Arm9 S3C2440 processor
  - Operating system: WinCE 5.0
  - Program language: C#
  - Input: GPS Sensor (position), Digital Compass (heading), Distance Sensor & water probes
  - Output: Sending Command to Atmega128 control board
  - Data Saving to SD card

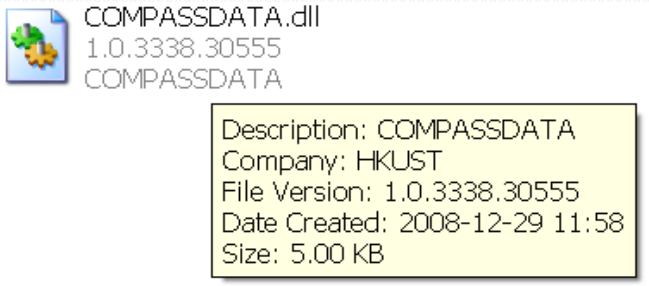
Hardware

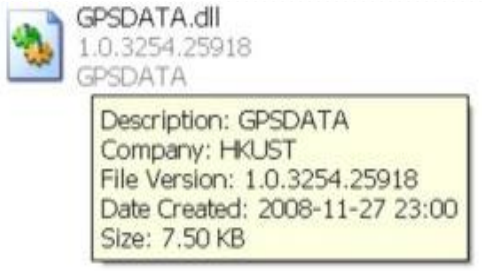
- Atmega128 processor
  - Program language: C



Hardware

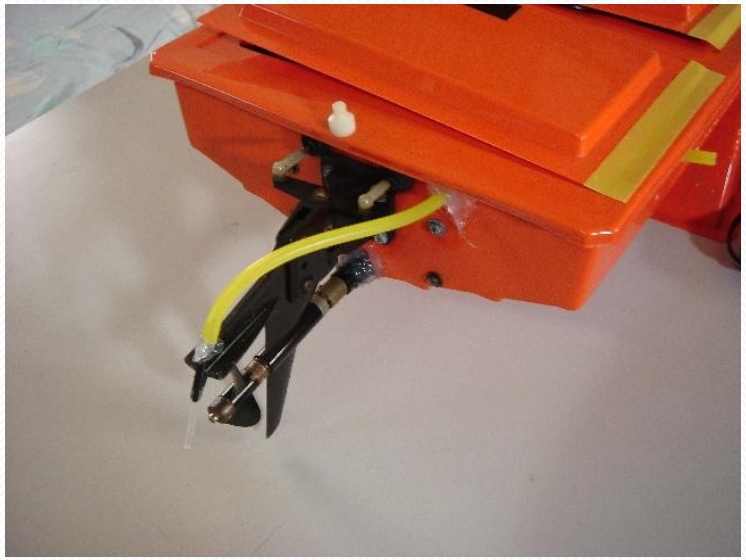
- Navigation Components
  - Digital Compass
  - GPS





Hardware

- Motor System
  - Servo Motor: Rudder
  - DC Motor: Propeller
  - Motor Driver, Water Cooling System

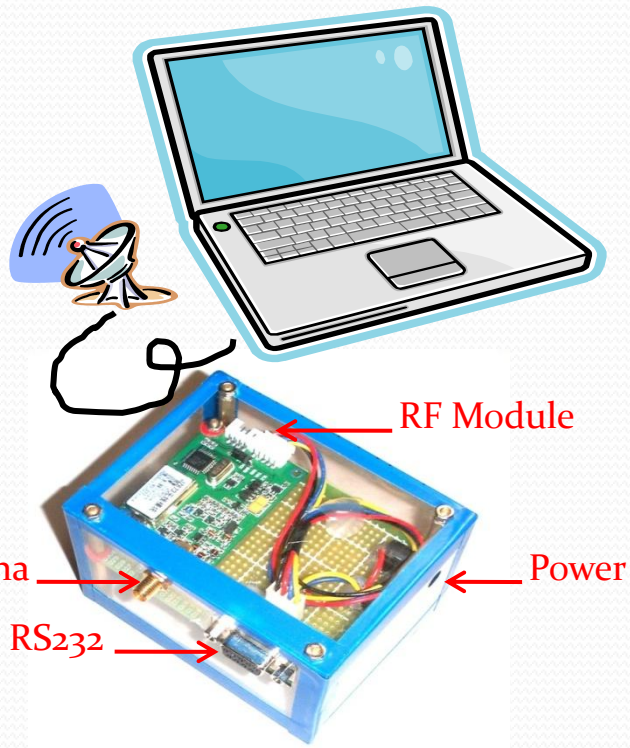


PC Base Station

420D\r
85B\r
22.3415667N\r
114.233124E\r
29H

RF_Interface

Speed & Rudder Angle



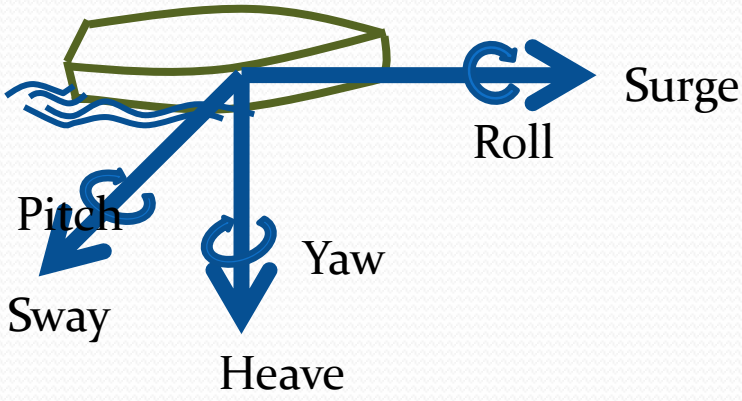
Waypoint Manager

Data Display

Excel Writer

Mathematic Model

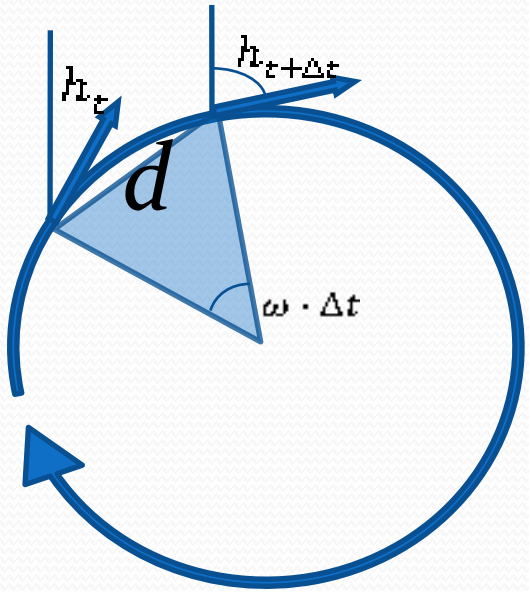
3 degree of Freedom



Earth fixed coordinate system

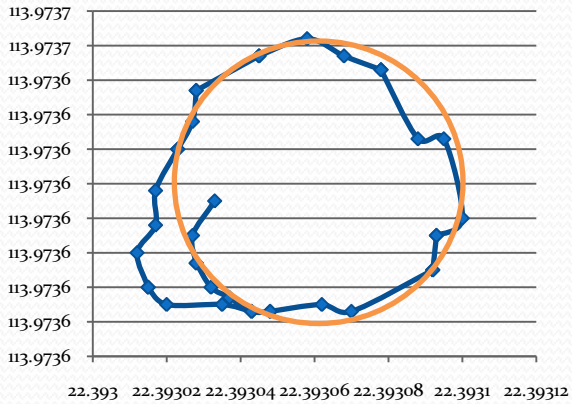
$$\begin{cases} X_{current} = (longi_{current} - longi_{origin}) \times 111111 \\ Y_{current} = (lati_{current} - lati_{origin}) \times 111111 \times \cos(longi_{current}) \\ dis_{A-B} = \sqrt{(X_A - X_B)^2 + (Y_A - Y_B)^2} \end{cases}$$

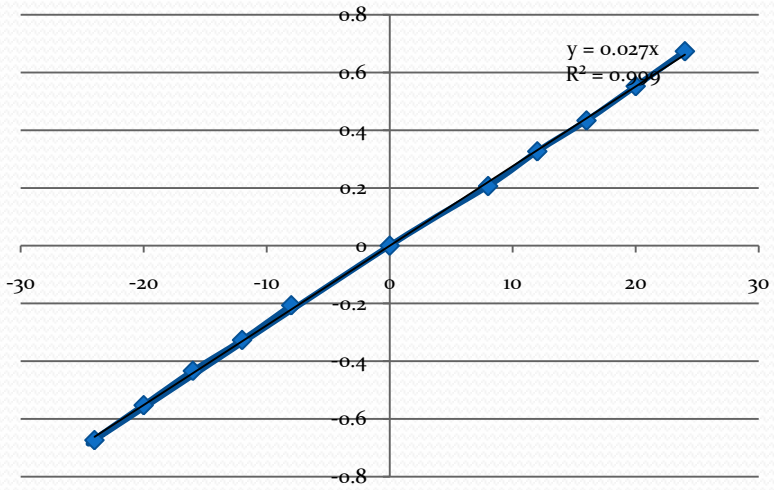
Motion Estimation

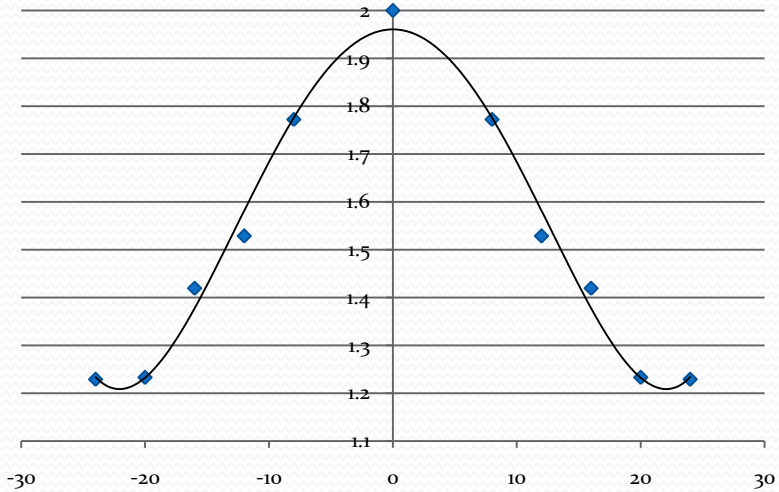


$$\mathbf{x}_k = f\left(\begin{bmatrix} X_{k-1} \\ Y_{k-1} \\ h_{k-1} \end{bmatrix}, \begin{bmatrix} v_k \\ \theta_k \\ o \end{bmatrix}\right) + \mathbf{w}_k = \begin{bmatrix} X_{k-1} + d(\theta_k) \times \sin(\omega in_k)/2 + h_{k-1}) \\ X_{k-1} + d(\theta_k) \times \cos(\omega os_k)/2 + h_{k-1}) \\ h_{k-1} + \omega(\theta_k) \end{bmatrix} + \mathbf{w}_k$$

Motion Estimation







Kalman Filter

Estimation Phase:

$$\mathbf{x}_{k|k-1} = \mathbf{F}_k \mathbf{x}_{k-1|k-1} + \mathbf{B}_{k-1} \mathbf{U}_{k-1} + \mathbf{w}_k$$

$$\mathbf{P}_{k|k-1} = \mathbf{F}_k \mathbf{P}_{k-1|k-1} \mathbf{F}_k^{\mathrm{T}} + \mathbf{Q}_{k-1}$$

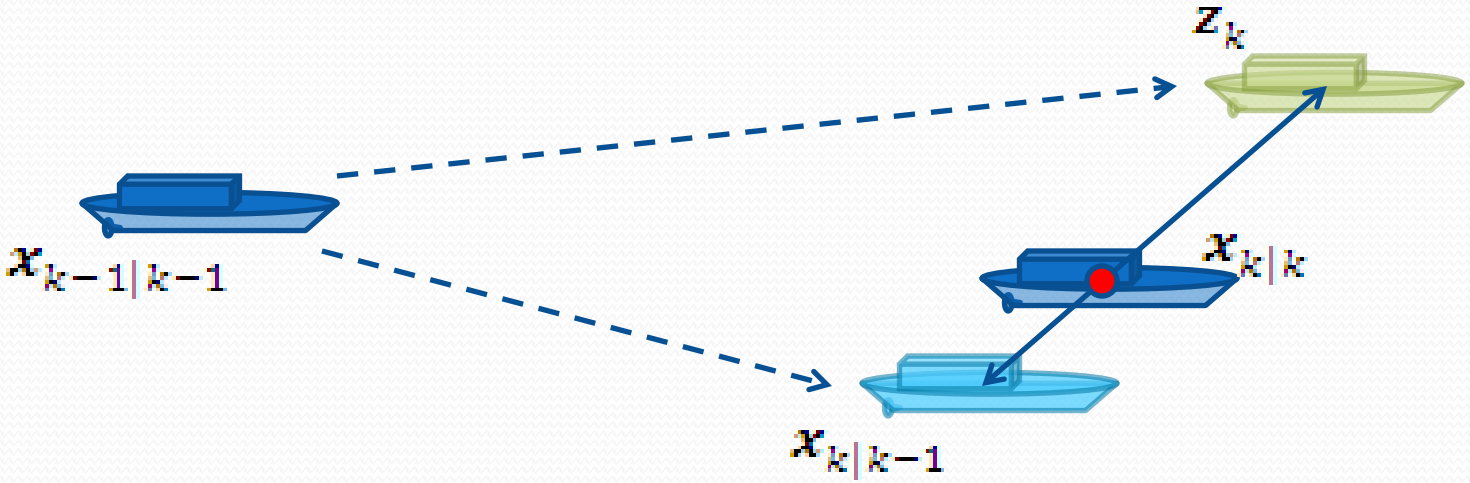
Update Phase:

$$\mathbf{K}_k = \mathbf{P}_{k|k-1} \mathbf{H}_k^{\mathrm{T}} (\mathbf{H}_k \mathbf{P}_{k|k-1} \mathbf{H}_k^{\mathrm{T}} + \mathbf{R}_k)^{-1}$$

$$\mathbf{x}_{k|k} = \mathbf{x}_{k|k-1} + \mathbf{K}_k (\mathbf{z}_k - \mathbf{H}_k \mathbf{x}_{k|k-1})$$

$$\mathbf{P}_{k|k} = (\mathbf{I} - \mathbf{K}_k \mathbf{H}_k) \mathbf{P}_{k|k-1}$$

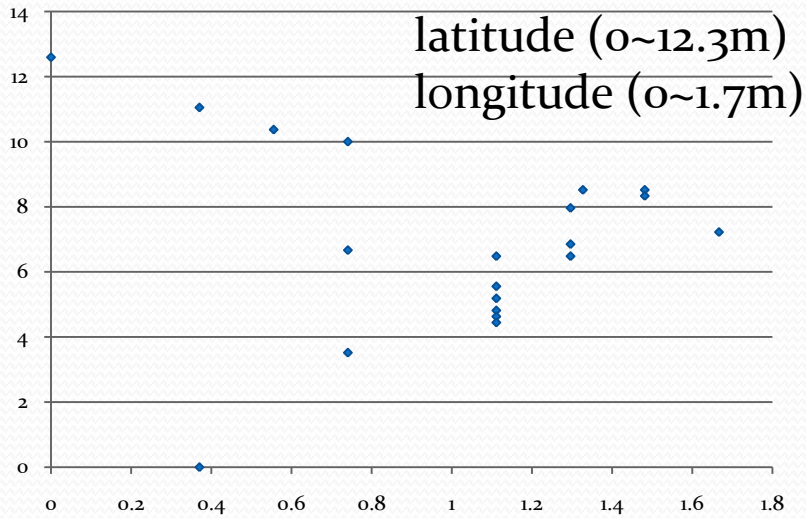
Kalman Filter

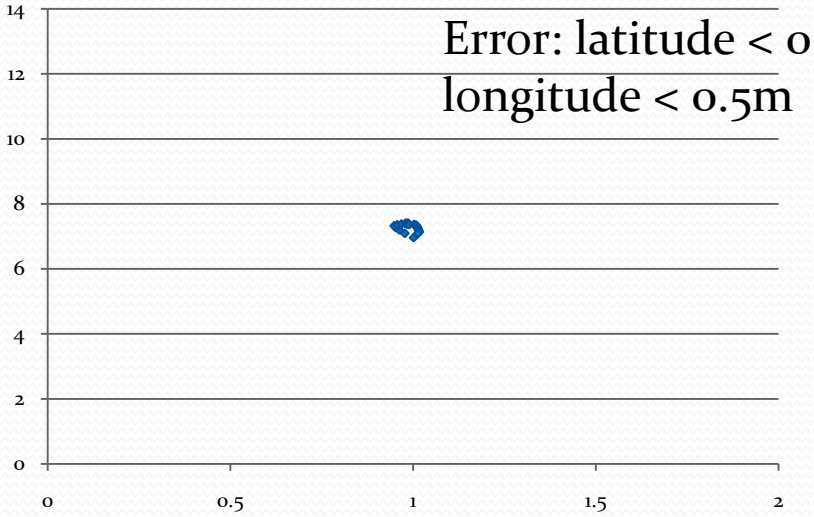


Kalman Filter Pseudo-code

```
Set R; //measurement noise
Set Q; //process noise, tuned value
x(1,1)=z(1);
p(1,1)=R;
for k=2:n;
        x(k,k-1)=x(k-1,k-1);
        p(k,k-1)=p(k-1,k-1)+Q;
        kg(k)=p(k,k-1)/(p(k,k-1)+R);
        x(k,k)=x(k,k-1)+kg(k)*(z(k)-x(k,k-1));
        p(k,k)=(1-kg(k))*p(k,k-1);
end;
```

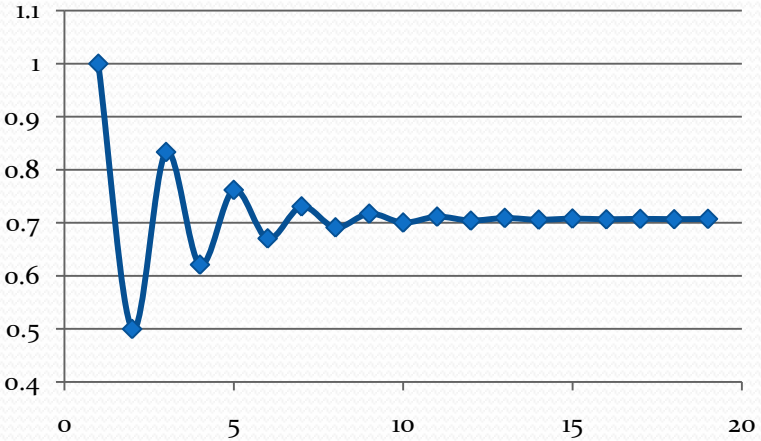
Static GPS Test



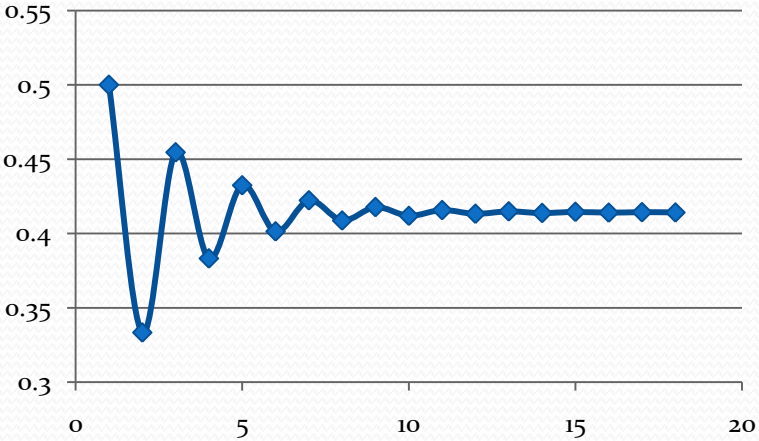


Static test before Kalman Filter

After Kalman Filter

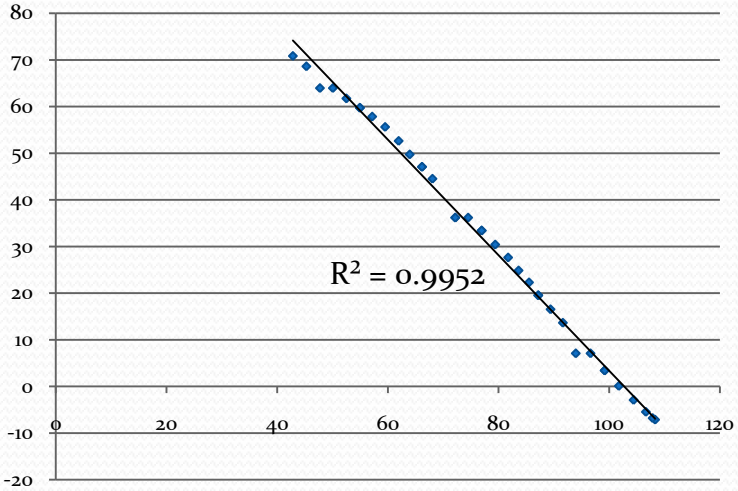


$P_{k|k-1}$

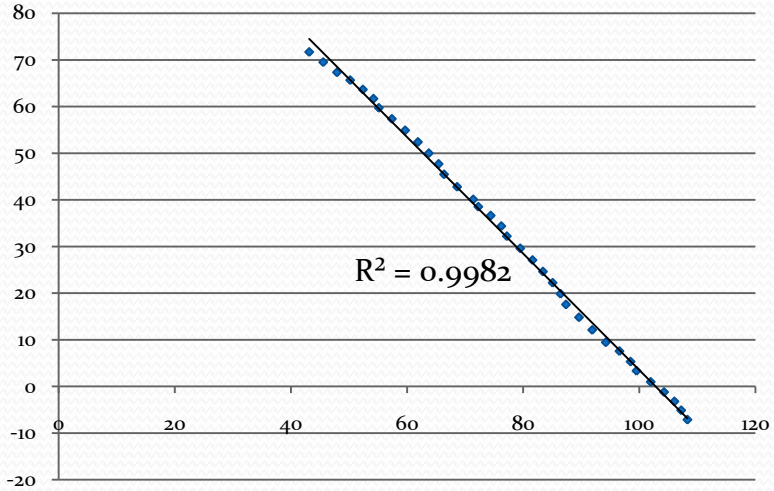


K_k

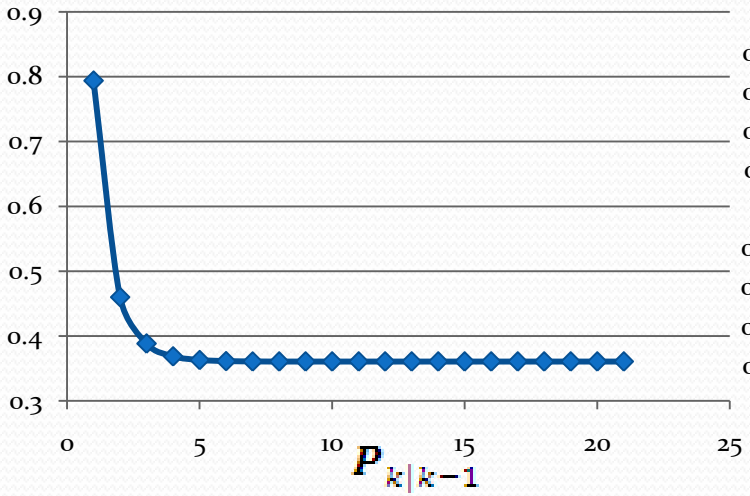
Constant speed motion test

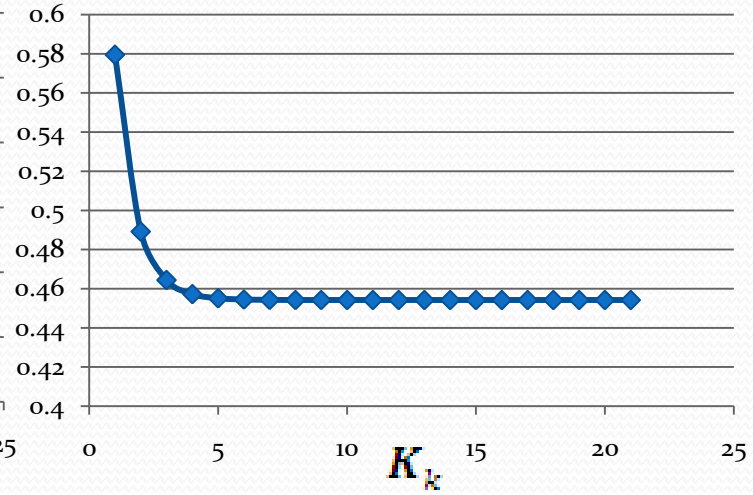


Constant speed test before KF

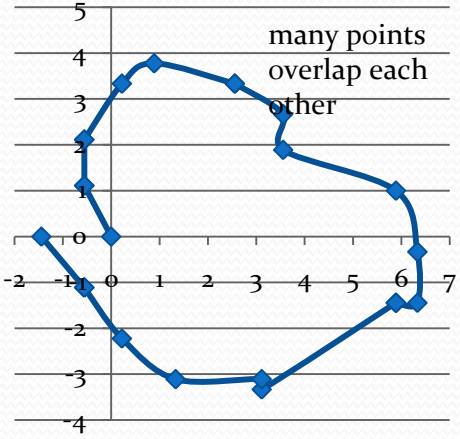


After KF

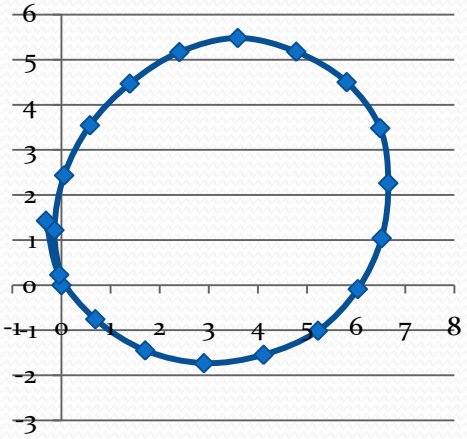




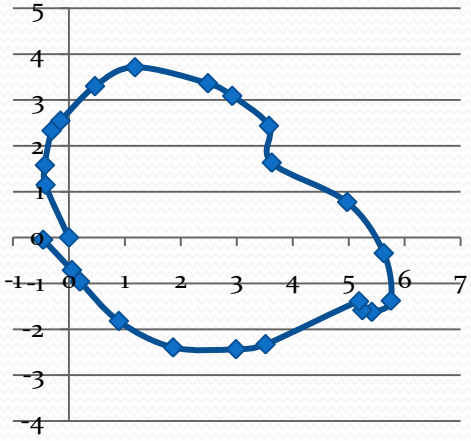
Uniform circular motion test



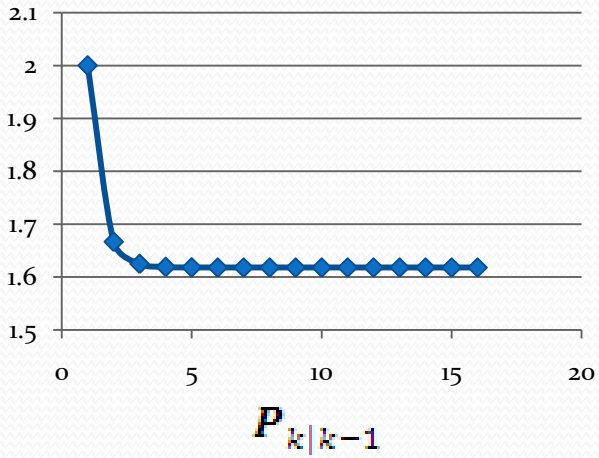
Circular motion test raw data

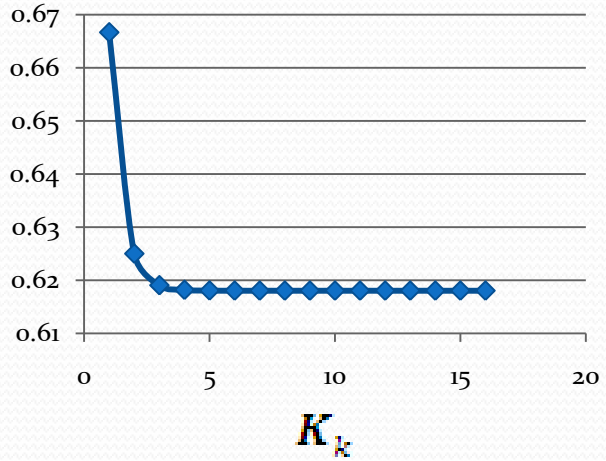


Pure estimation



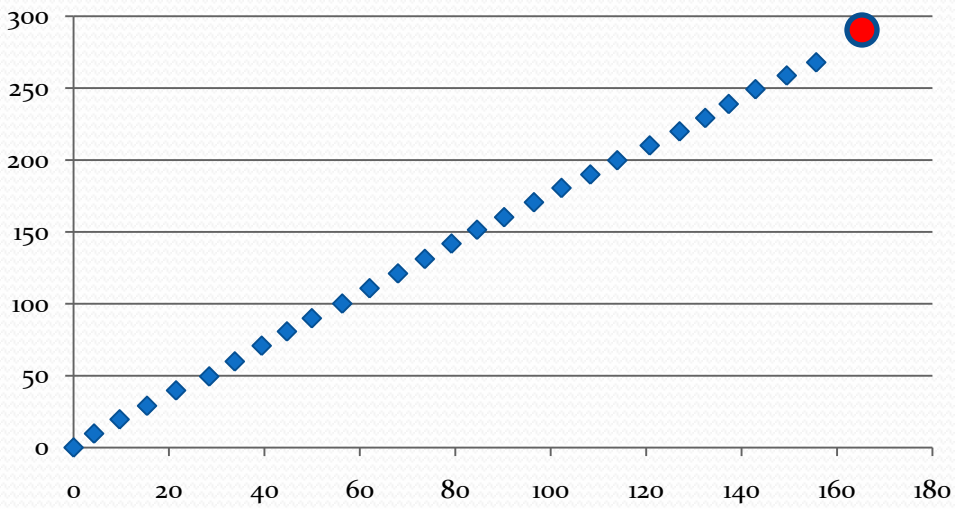
After KF



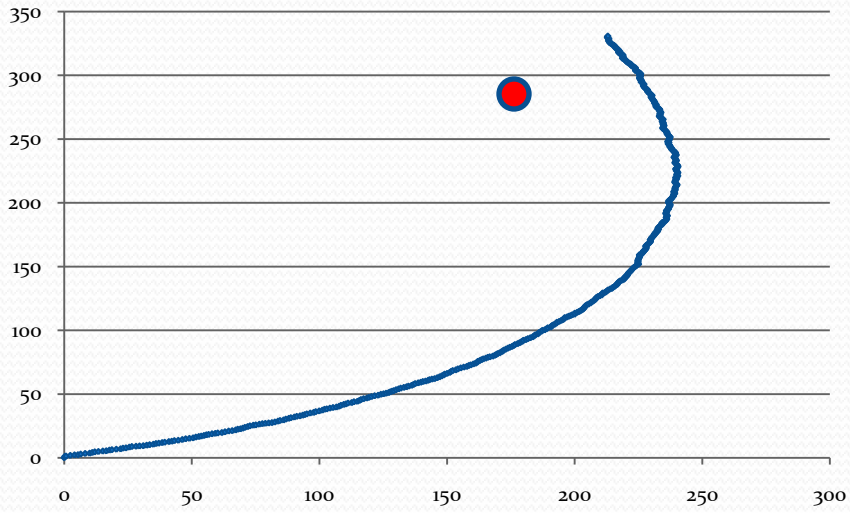


Simulation

A simulating water flow (0.5 m/s, to the south) is added.

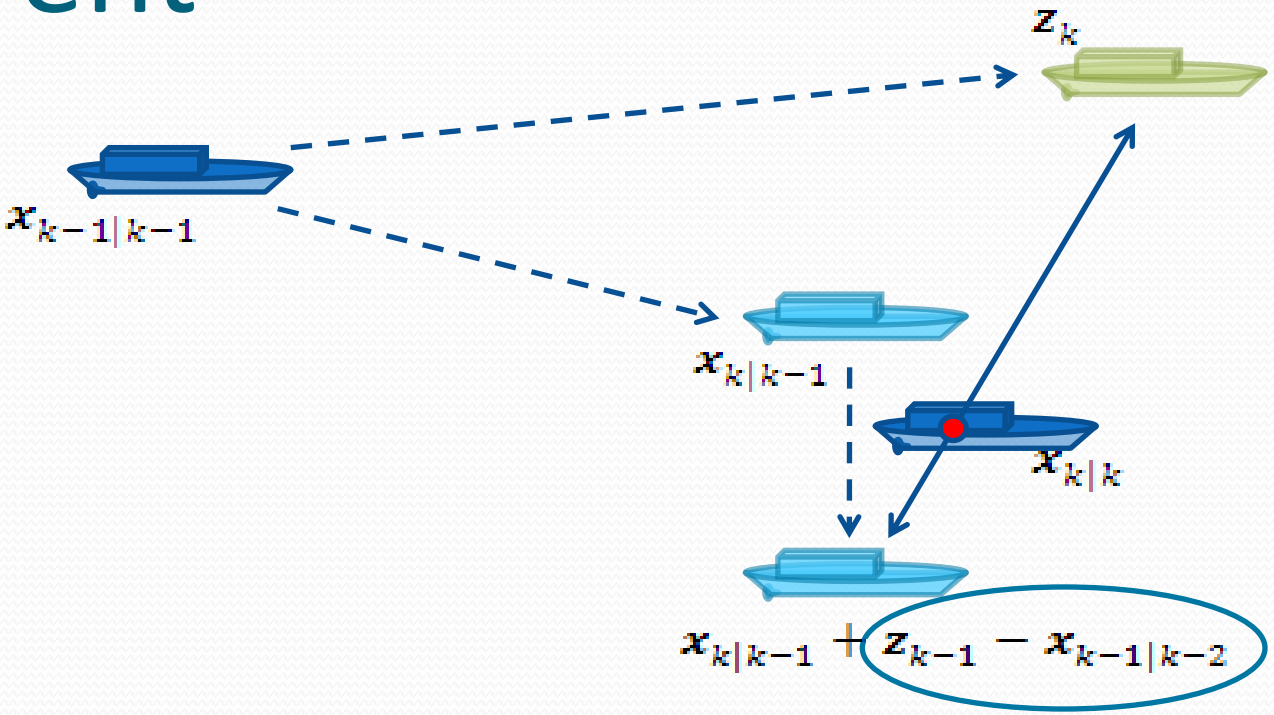


A simulating water flow (2 m/s, to the south) is added.



*Destination: (170, 290)

Kalman filter adjusted by water current

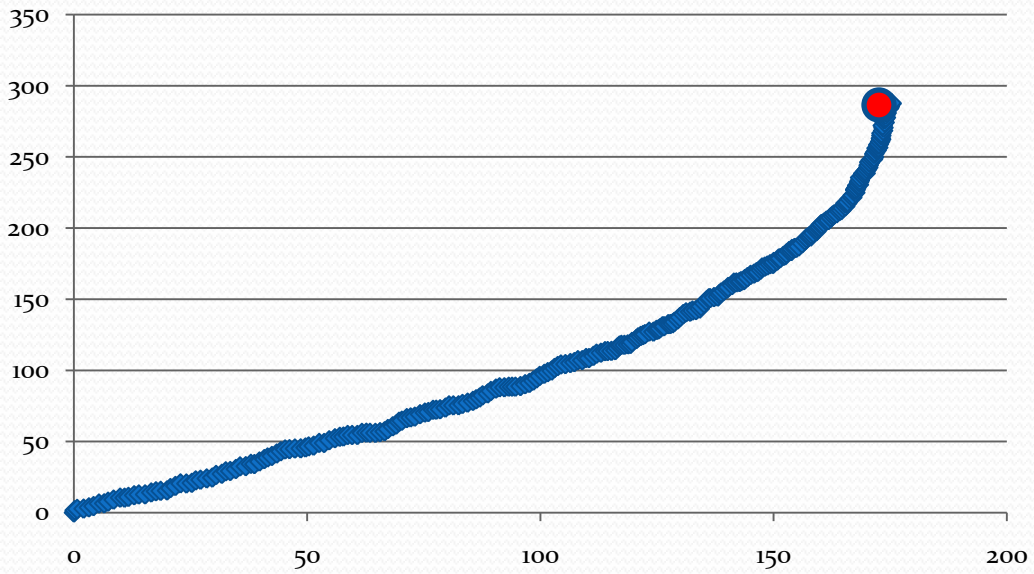


Modified Update Phase Equation:

$$x_{k|k} = x_{k|k-1} + z_{k-1} - x_{k-1|k-2} + K_k(z_k - h(x_{k|k-1} + z_{k-1} - x_{k-1|k-2}))$$

Final Simulation

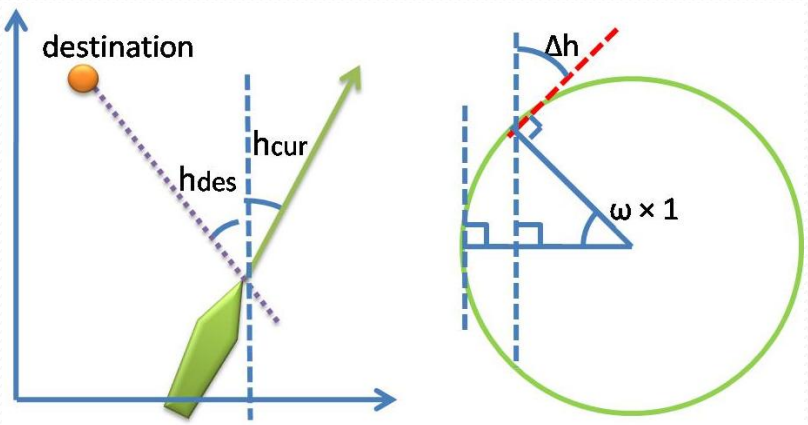
A simulating water flow (2 m/s, to the south) is added.



*Destination: (170, 290)

Control Command

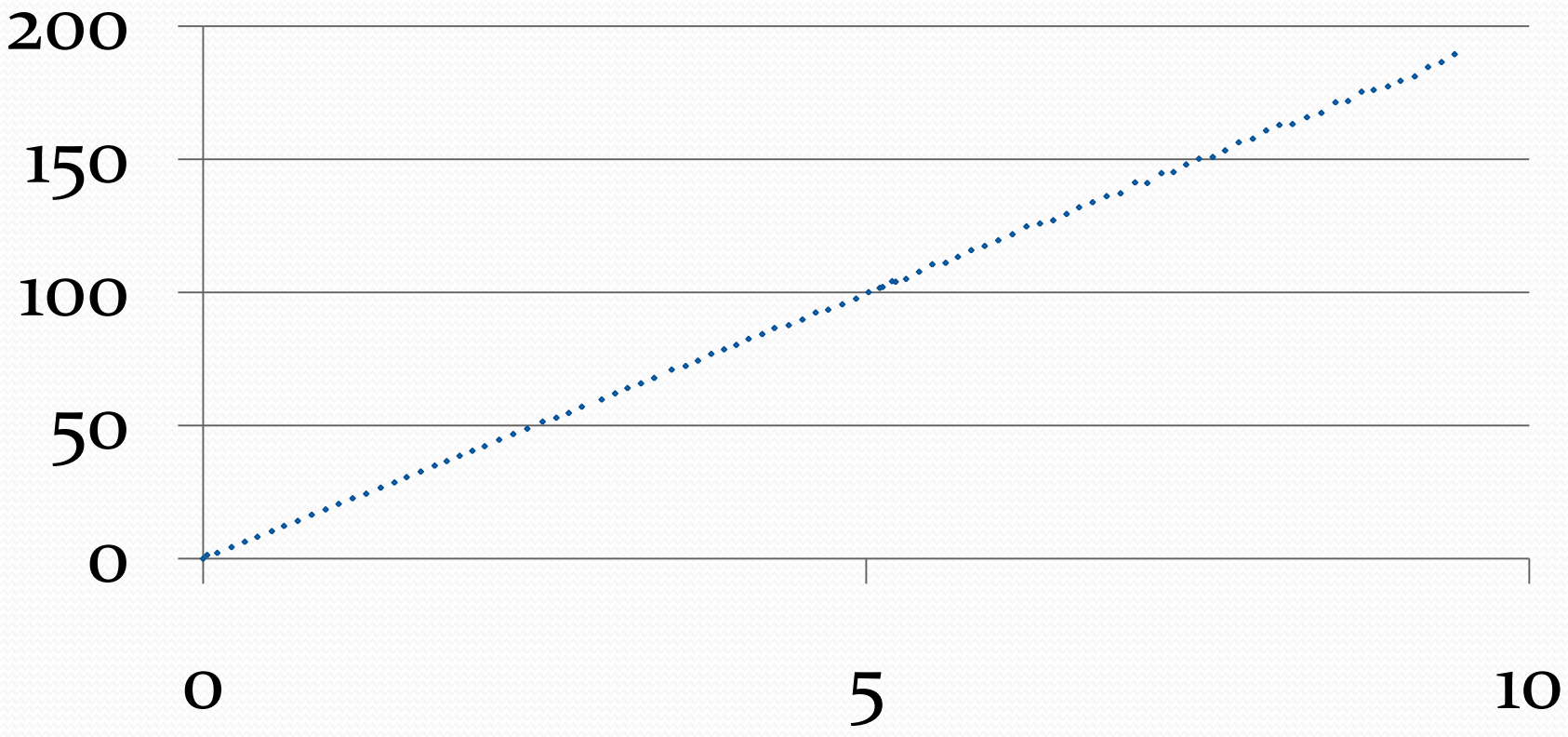
$$\alpha_{desired} = \begin{cases} 0, & X_{current} = X_{destination} \\ \frac{\pi}{2} - \tan^{-1}\frac{Y_{current} - Y_{destination}}{X_{current} - X_{destination}}, & X_{current} > X_{destination} \\ -\frac{\pi}{2} - \tan^{-1}\frac{Y_{current} - Y_{destination}}{X_{current} - X_{destination}}, & X_{current} < X_{destination} \end{cases}$$



$$\Delta h = \omega(\theta) \times 1 = \omega(\theta)$$

$$\theta_{\text{need-to-be}} = \omega^{-1}(h_{\text{need}})$$

Resent Real Navigation Test

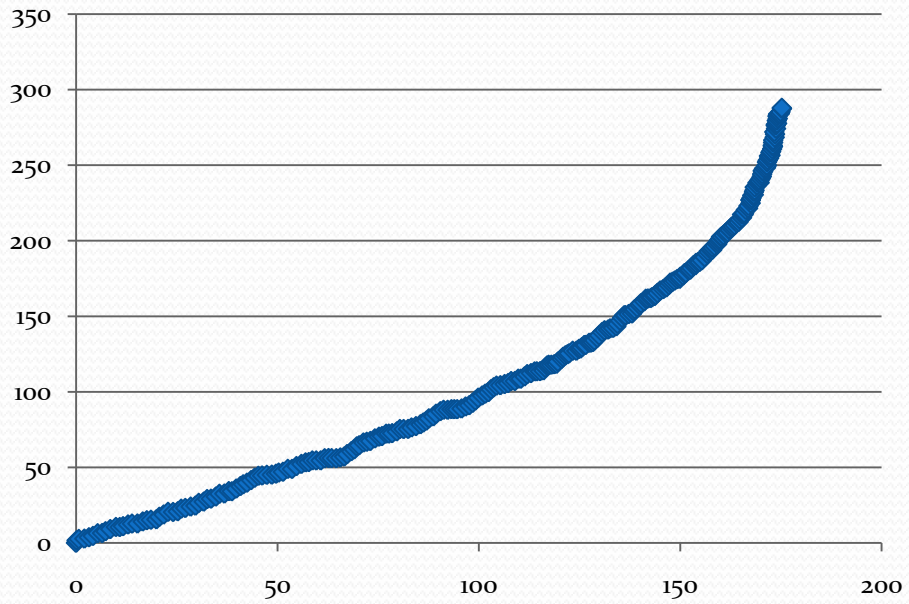


*Recorded from HKUST Sea Front

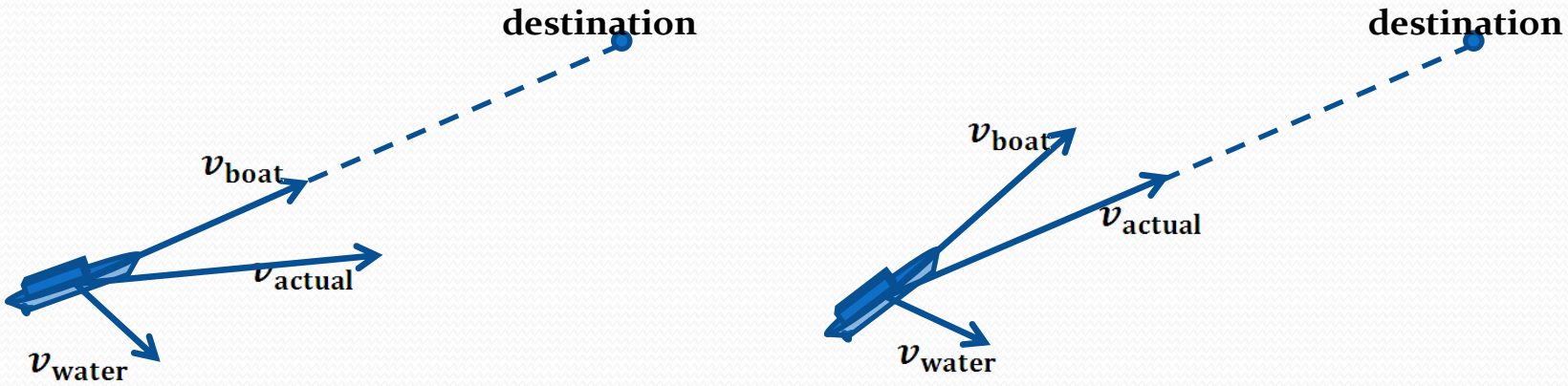
Defects of the Current Control Model

Follow-the-carrot Control Model

- The path is curved by water flow
- It is efficient in static water but not in dynamic water



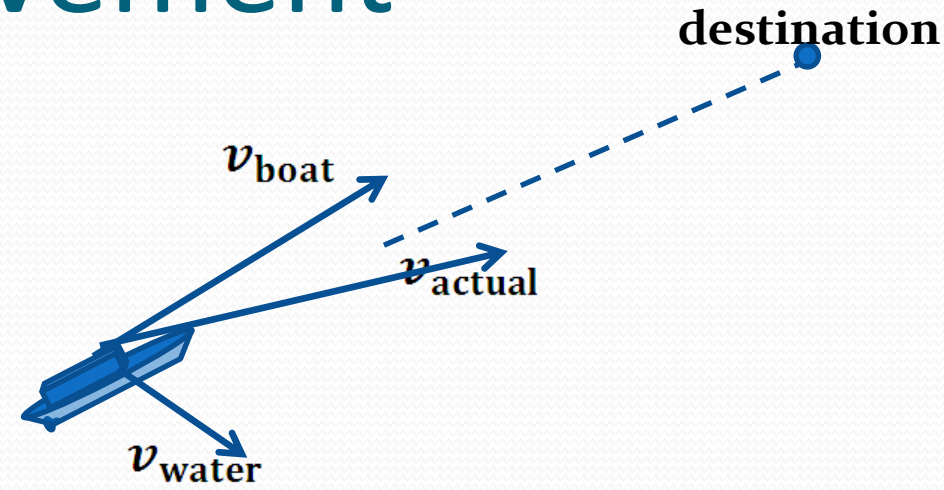
Improvement



$$\alpha_k = \begin{cases} 0, & X_k = X_{k-1} \\ \frac{\pi}{2} - \tan^{-1}\frac{Y_k - Y_{k-1}}{X_k - X_{k-1}}, & X_{k-1} < X_k \\ -\frac{\pi}{2} - \tan^{-1}\frac{Y_k - Y_{k-1}}{X_k - X_{k-1}}, & X_{k-1} < X_k \end{cases}$$

$$\theta_{rudder} = K_p(\alpha_{desired} - \alpha_k) + K_d(\dot{\alpha}_{desired} - \dot{\alpha}_k) + K_i \int (\alpha_{desired} - \alpha_k)dt$$

Improvement

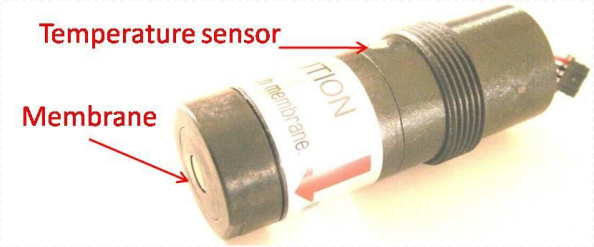


$$\alpha_{current} = h_{current} + \frac{\alpha_k - h_{current}}{1 + \delta}$$

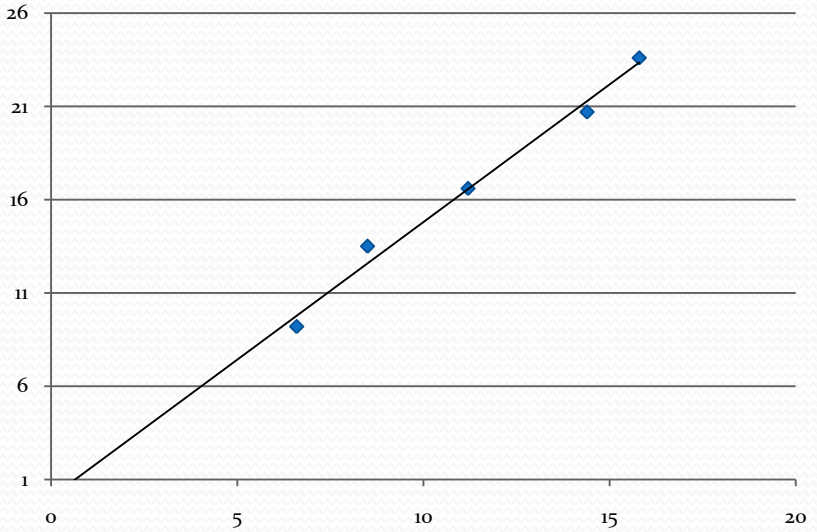
$$\frac{1}{\delta} \propto \text{Water Speed}$$

$$\theta_{rudder} = K_p(\alpha_{desired} - \alpha_{current}) + K_d(\dot{\alpha}_{desired} - \dot{\alpha}_{current}) + K_i \int (\alpha_{desired} - \alpha_{current})dt$$

Add Chemical Sensors



*KDS-25 dissolved oxygen & temperature sensor



Cathode – positive pole reaction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Anode – negative pole reaction: $2Pb + 4OH^- \rightarrow 2PbO + 2H_2O + 4e^-$

Total reaction: $O_2 + 2Pb \rightarrow 2PbO$

Future Work

- Larger boat platform
- Carry more chemical sensors
- More batteries to longer the working time
- Stronger antenna to communicate longer
- Even can go underwater

Acknowledgement

- Wholehearted gratefulness to Prof. Zexiang Li
- My partner: Mingyu Wang
- Special thanks to Prof. Xiaoyuan Li
- Thanks for your time

Some Achievements

- Won 2nd Place Hang Seng Green Challenge Competition
- Finalist of 2009 President's Cup

Q & A