Indoor/Outdoor Pedestrian Navigation with an Embedded GPS/RFID/Self-contained Sensor System

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Research background (1)

- Location/direction-based Web services are widely available to provide local information such as maps, weather and nearby transportation. (ex. Google Maps and Yahoo! Maps)
- Portable PCs and PDAs (smart phones) are capable of rendering 3D urban landscape. (ex. Google Earth and Pocket Cortona)

Research background (2)

- Combination of location/direction-based services and a suite of 3D mapping software will provide highly intelligent navigation system.
- It is essentially important to acquire accurate position and direction to enable such navigation system.

Research targets

- In both indoor/outdoor environments, to achieve stride-level accuracy of positioning method.
  - It is realized by dead-reckoning method combined with RFID and GPS.
- To be implemented by an embedded computing system and provide pedestrian navigation services.

Proposed method:
Dead-reckoning based on walking locomotion

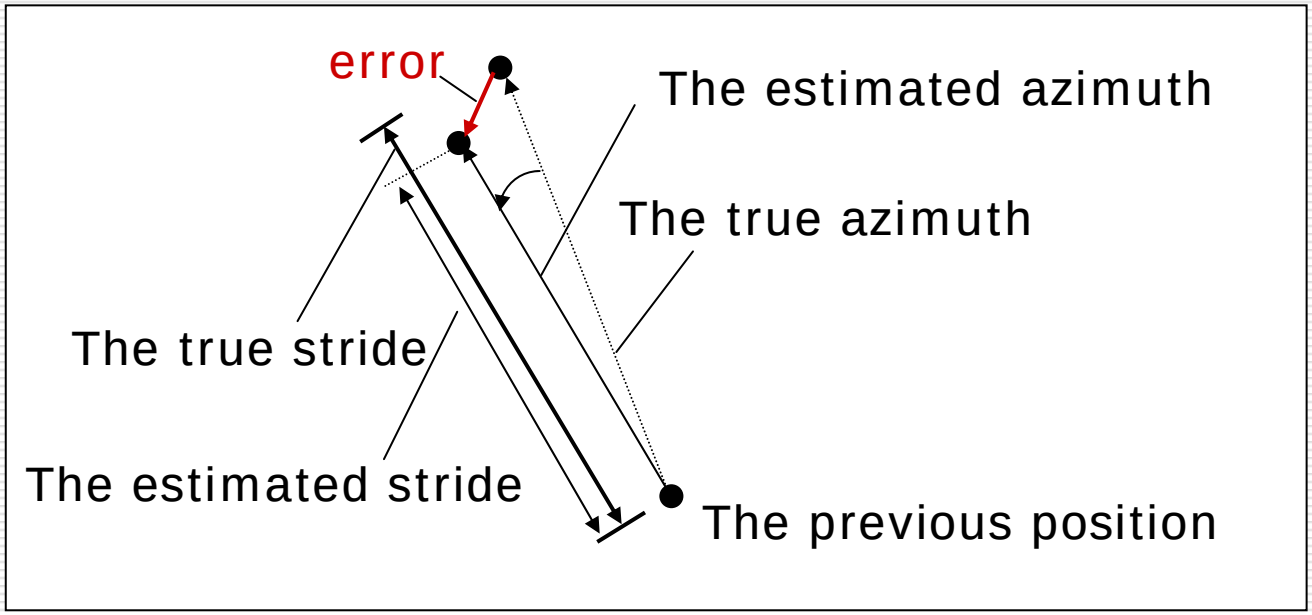
- Self-contained sensors (gyroscope, magnetometers and accelerometers) realize dead-reckoning based on human walking locomotion.
  - Partially proposed by our previous researches.
  - Dead-reckoning will work in both indoor/outdoor environments.

Proposed method:
Dead-reckoning based on walking locomotion

- Accuracy of dead-reckoning is vulnerable to accumulation of step-wise error and thus requires external sources of information about absolute position to correct such error.
  - First, error model of dead-reckoning is required.
  - Second, GPS and active RFID tag system are used as external position correction.

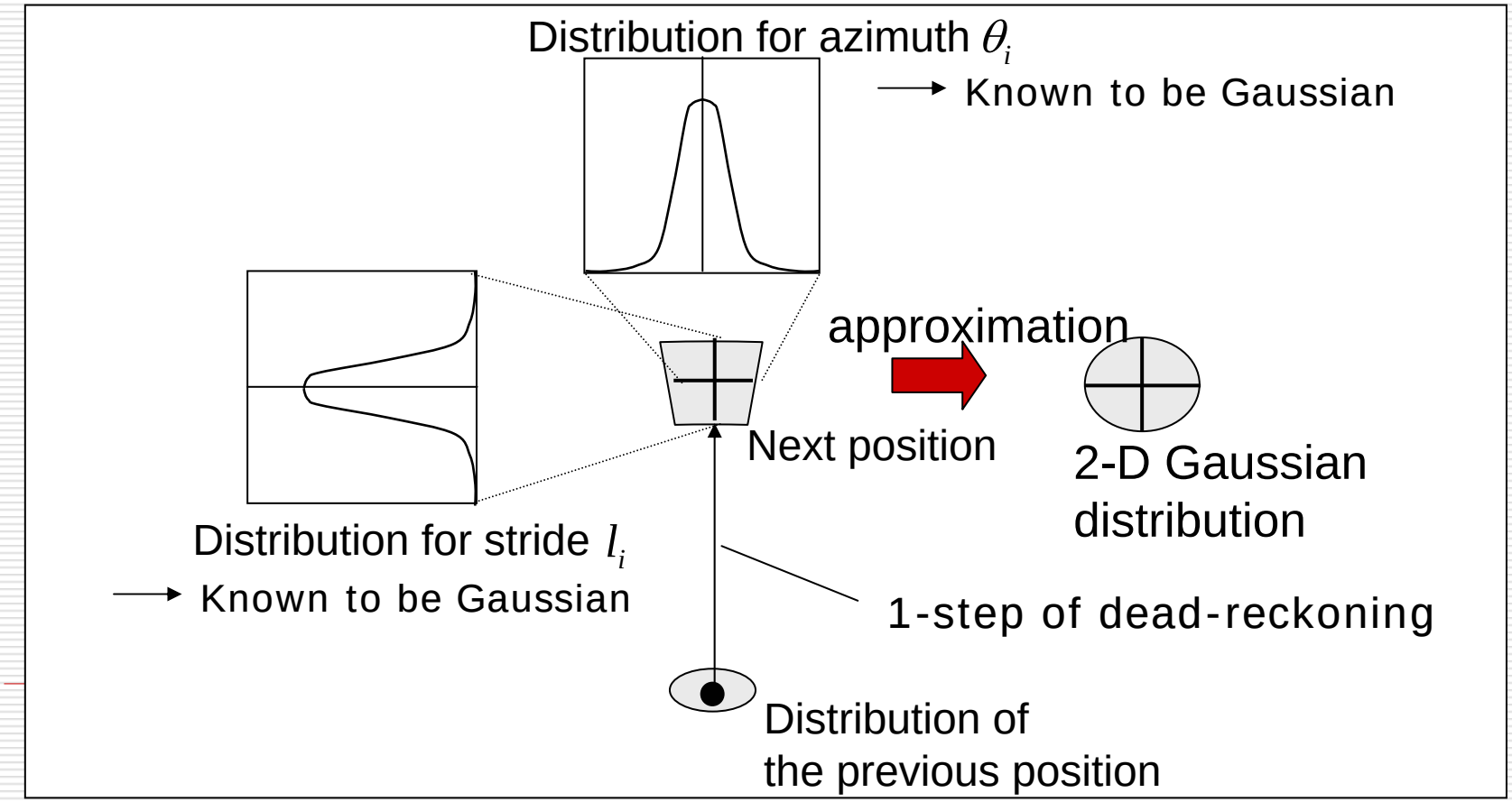
Proposed method: Error model of dead-reckoning

- The error of dead-reckoning is composition of that of azimuth and of stride.



Proposed method: Error model of dead-reckoning

- Combination of error caused by azimuth and stride are approximated by Gaussian distribution.



Proposed method: Error model of dead-reckoning

- Kalman filter is used to update the estimation of position and velocity.
  - The state vector:

$$\mathbf{s}_t = \left[\underbrace{x_t \quad y_t}_{\text{position}} \quad \underbrace{v_{x_t} \quad v_{y_t}}_{\text{velocity}}\right]^T$$

velocity → Estimated from acceleration during the walking locomotion

  - Update equations:

$$\mathbf{s}_{t+1|t} = \mathbf{s}_t + \mathbf{K}_t(\mathbf{O}_t - \mathbf{s}_t)$$

$$\mathbf{K}_t = \mathbf{P}_t(\mathbf{P}_t + \mathbf{R}_t)^{-1}$$

$$\mathbf{P}_{t+1|t} = \mathbf{P}_t - \mathbf{K}_t\mathbf{P}_t$$

$\mathbf{O}_t$ Observation of the state

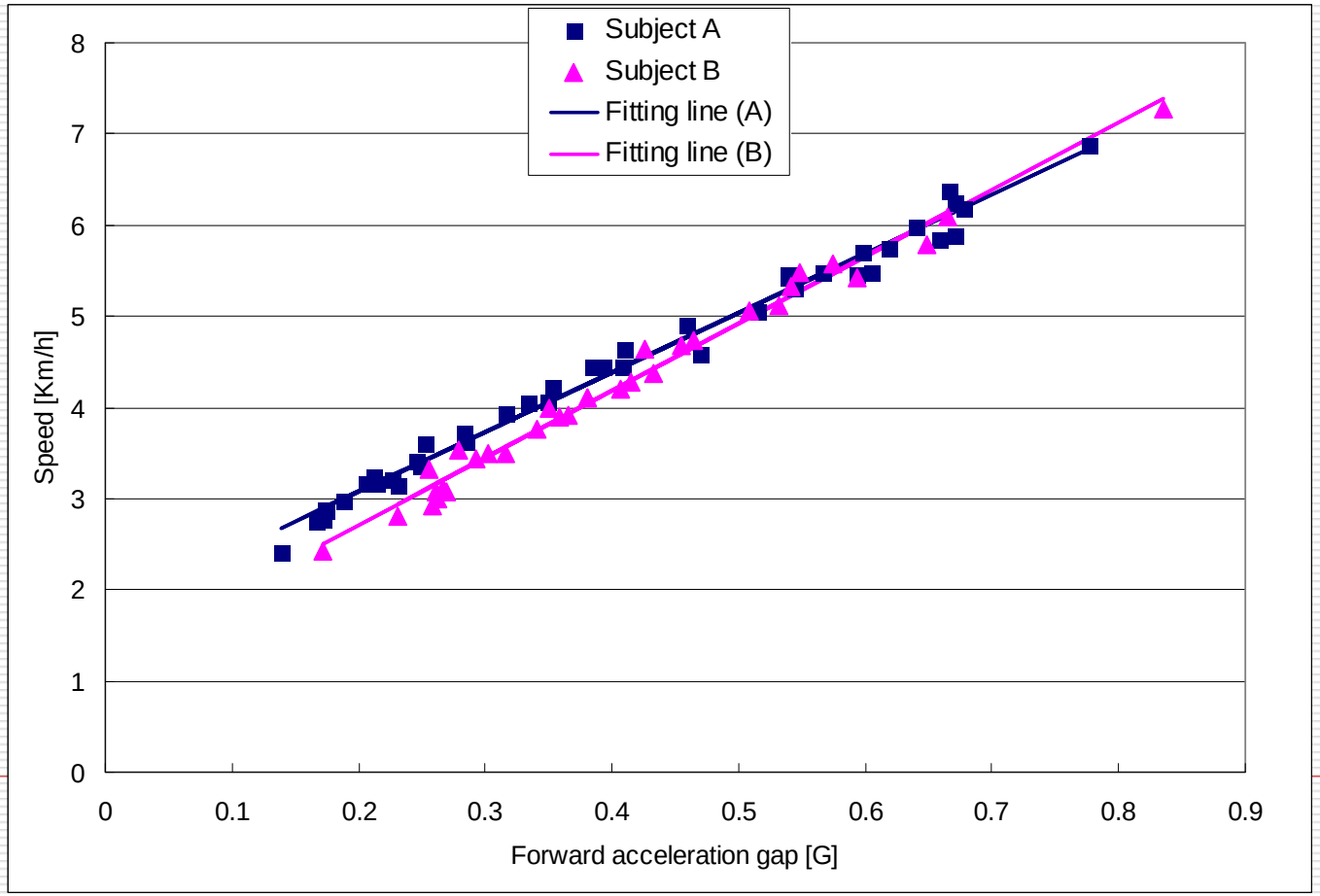
$\mathbf{K}_t$ Kalman gain

$\mathbf{P}_t$ Covariance matrix of the state vector

$\mathbf{R}_t$ Covariance matrix of the error of observation

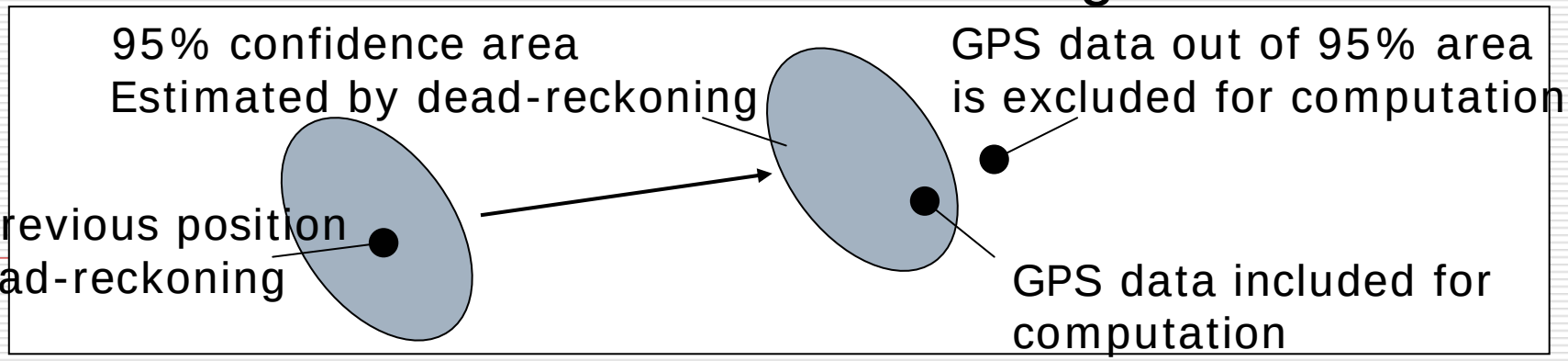
Proposed method: Estimation of pedestrian velocity

- The velocity and acceleration gap (amplitude) are highly correlated and estimated from the other.



Proposed method: Combination with external sources (1)

- GPS is used in outdoor environment.
  - Error of GPS has three components:
    - Error caused by multipath effect
    - Offset error caused by signal delays.
    - Random error (represented by Gaussian)
  - Multipath error can be reduced with combination of dead-reckoning.

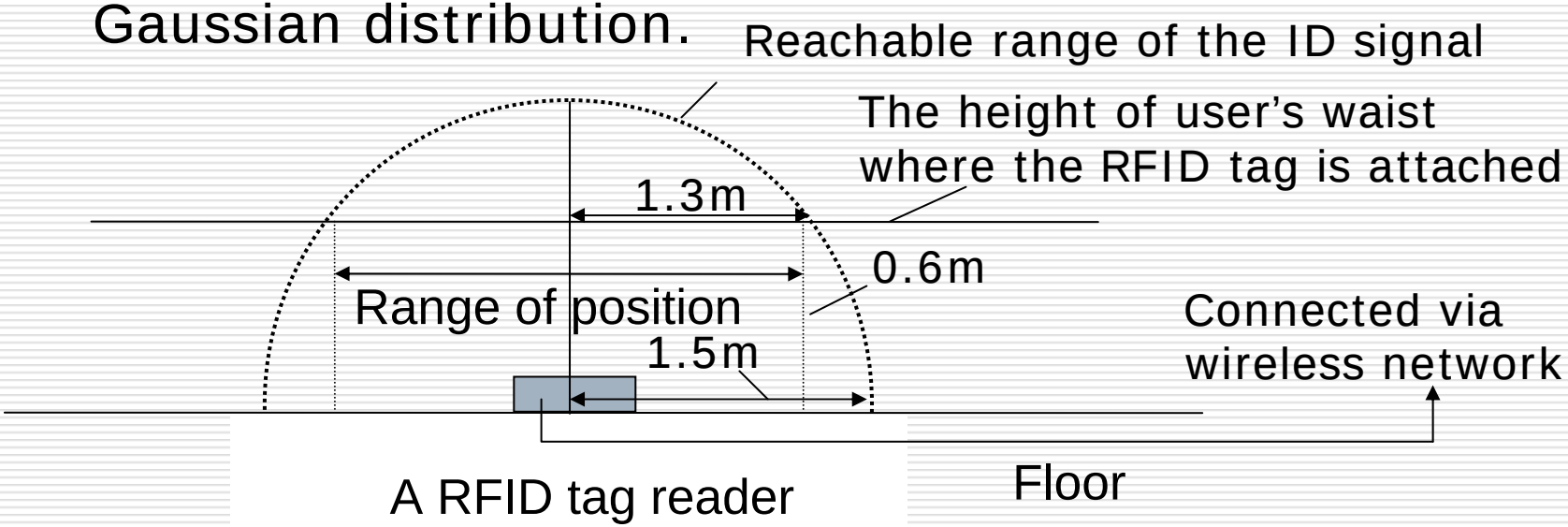


Proposed method: Combination with external sources (2)

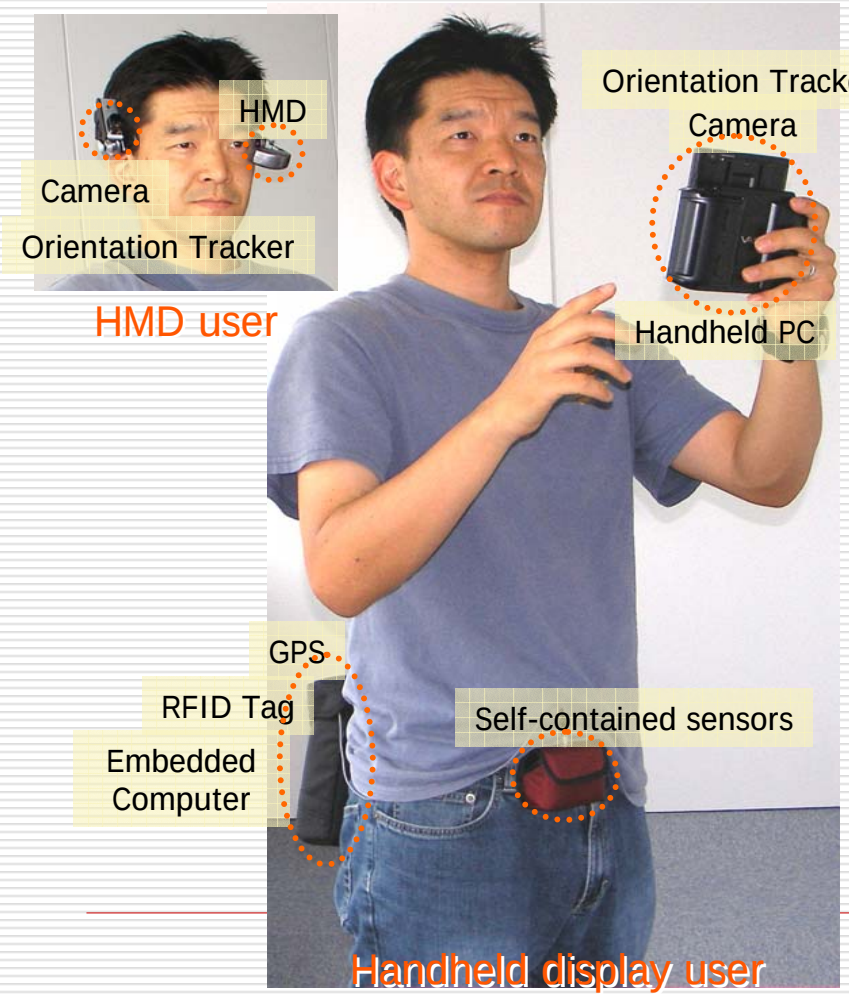
- GPS is used in outdoor environment.
  - Offset error can be measured by the fixed observation station whose location is exactly known.
  - Thus, remaining random error can be handled within Kalman filter framework since it has normal distribution.
  - Two measurements by GPS hints the position and velocity in the state vector.

Proposed method: Combination with external sources (3)

- Active RFID tag system is used to correct the pedestrian position.
  - Error of position can be represented by the Gaussian distribution.

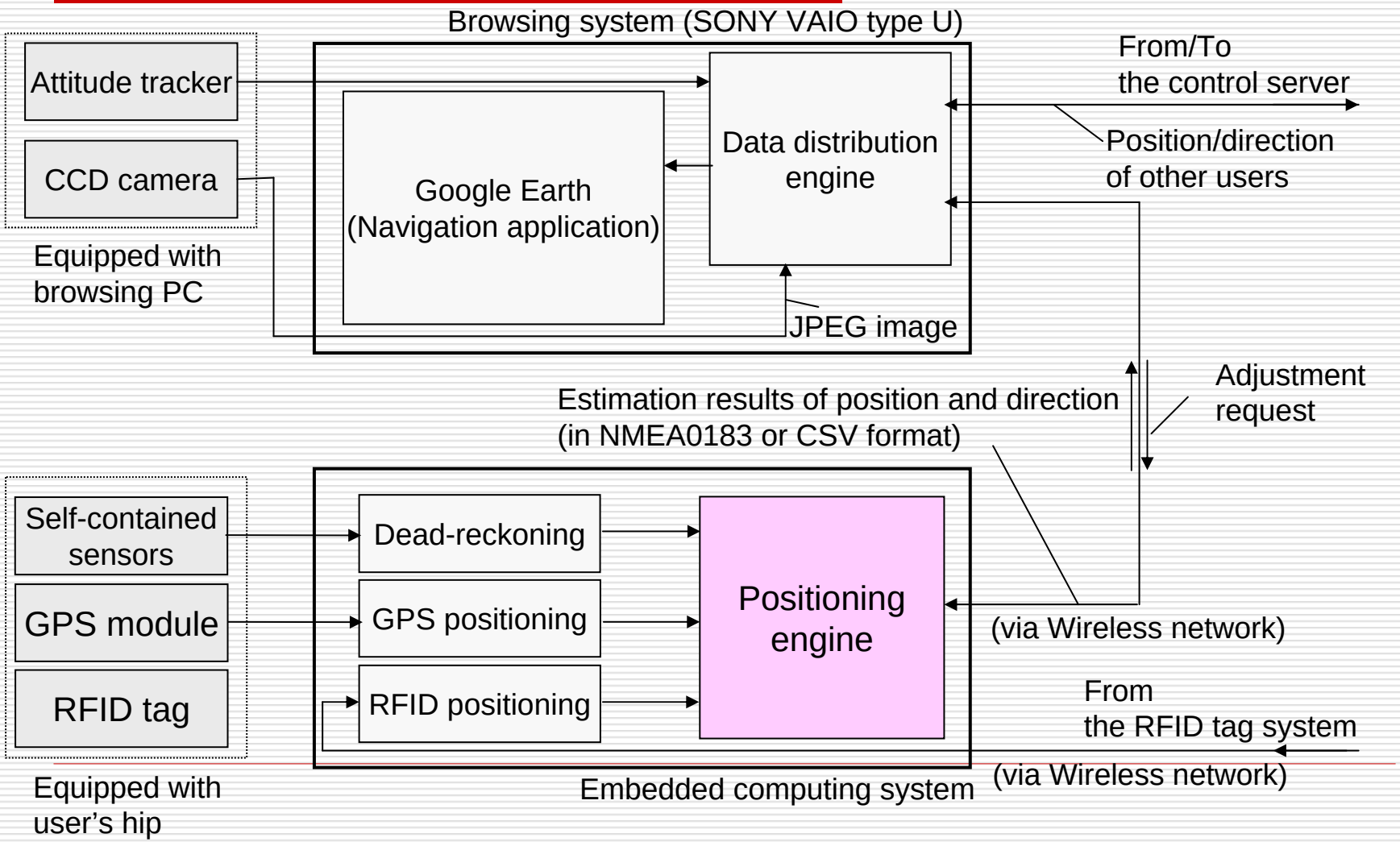


Implementation: Outlook of the system

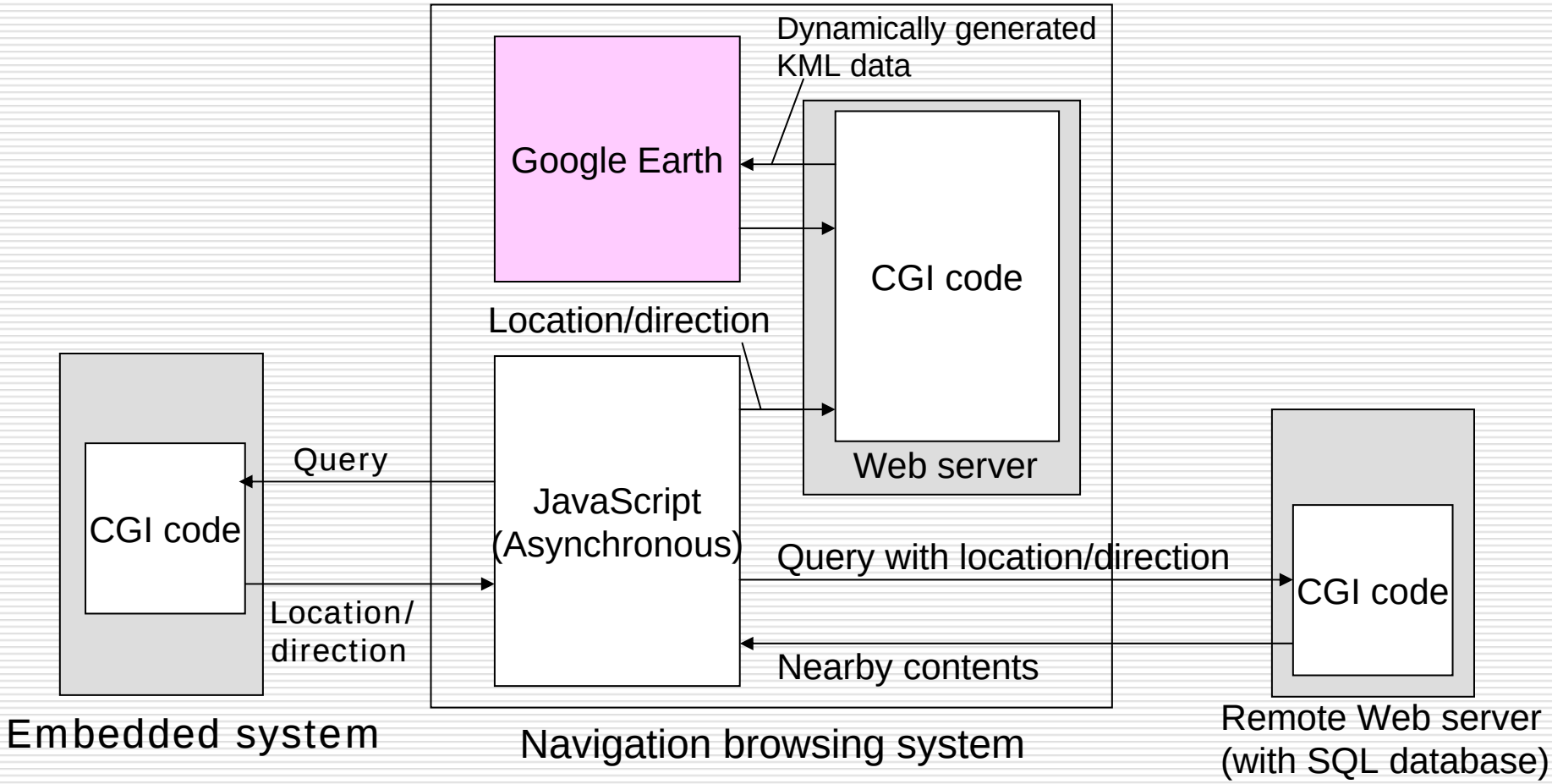


- The total system is implemented in an embedded computing system.
  - A browsing system is separately implemented.
  - HMD system and handheld system are implemented.

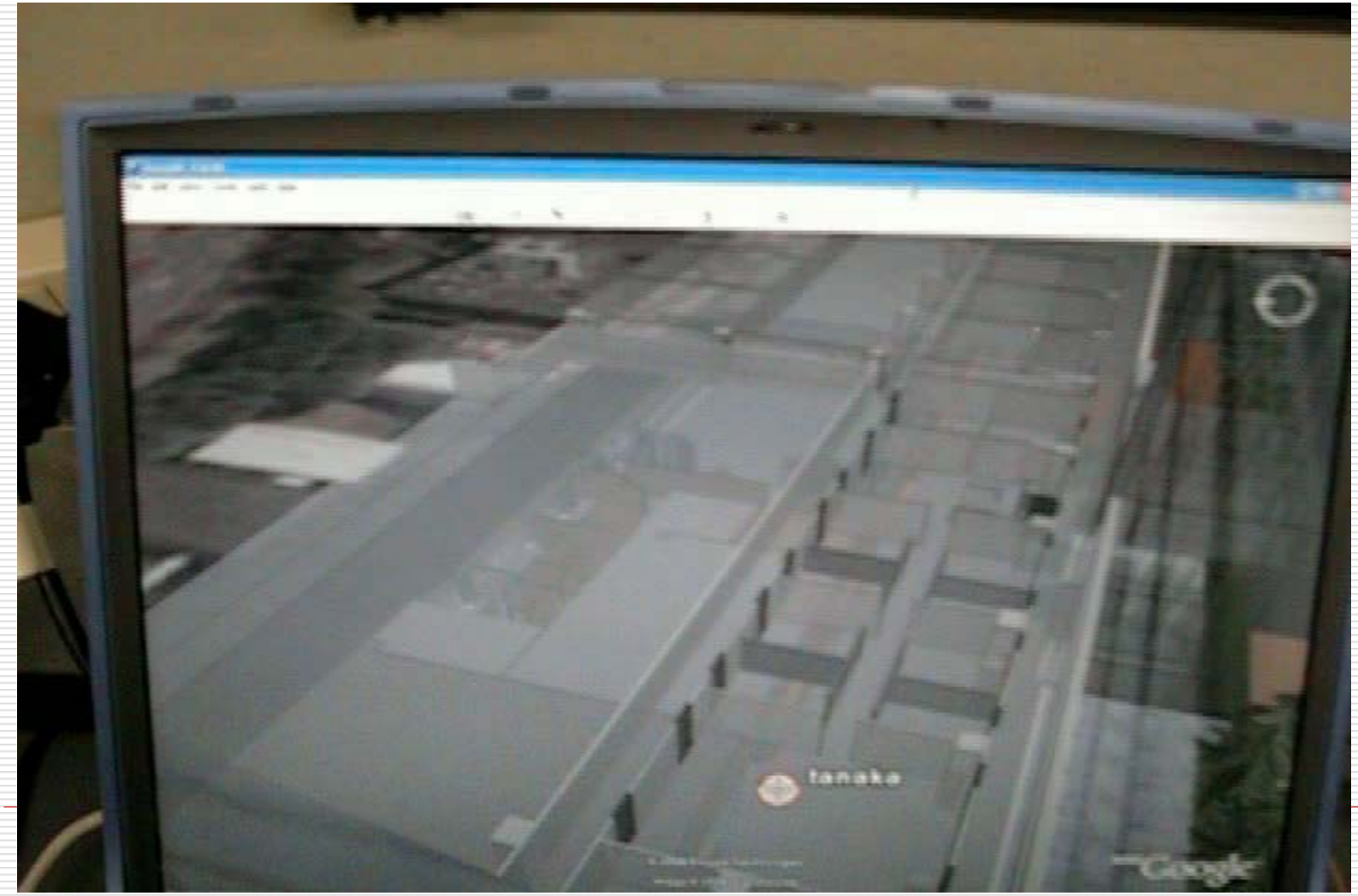
Implementation: Diagram of the system



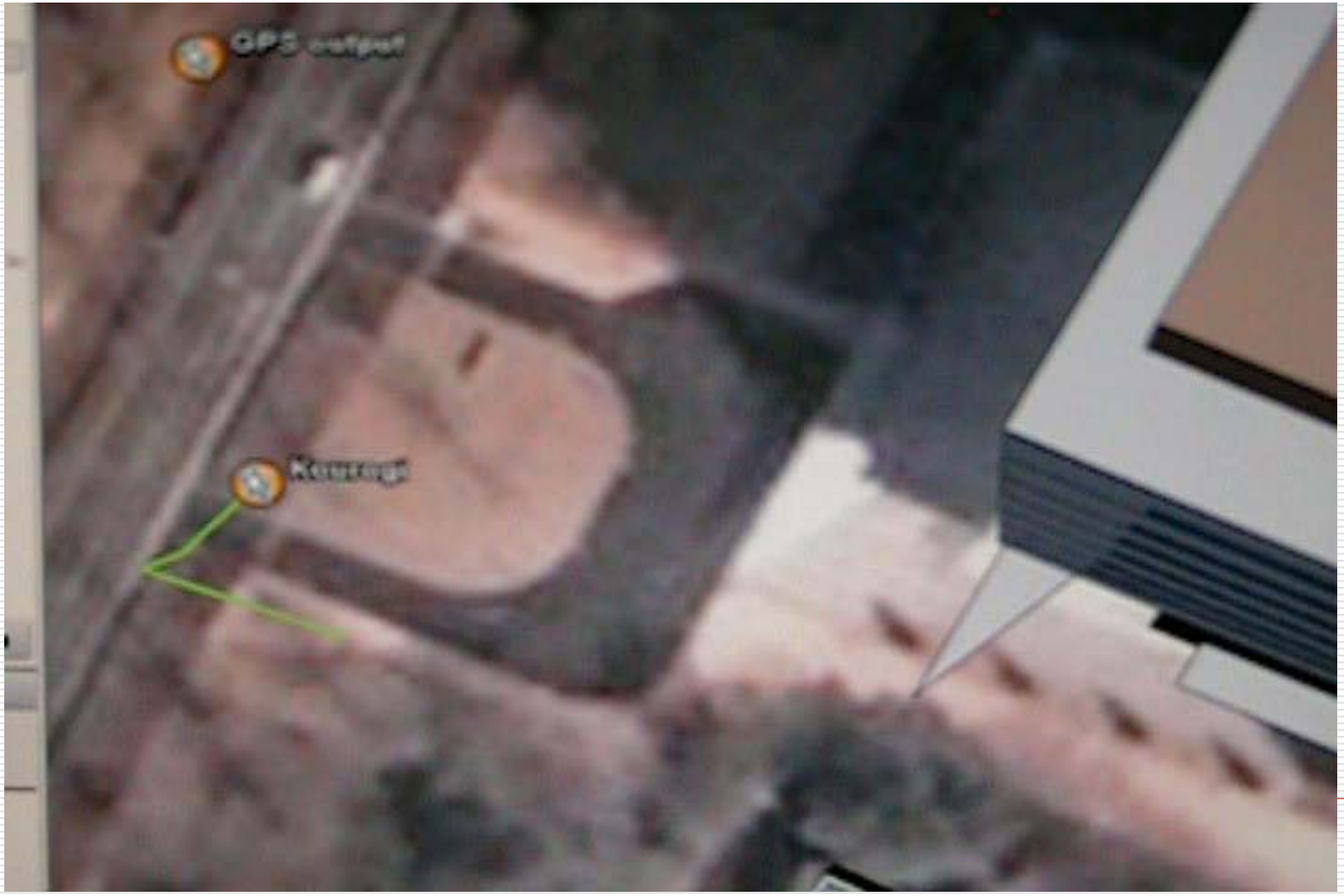
Implementation: Diagram of the system



Demo video:
Our system in actions (Indoors)

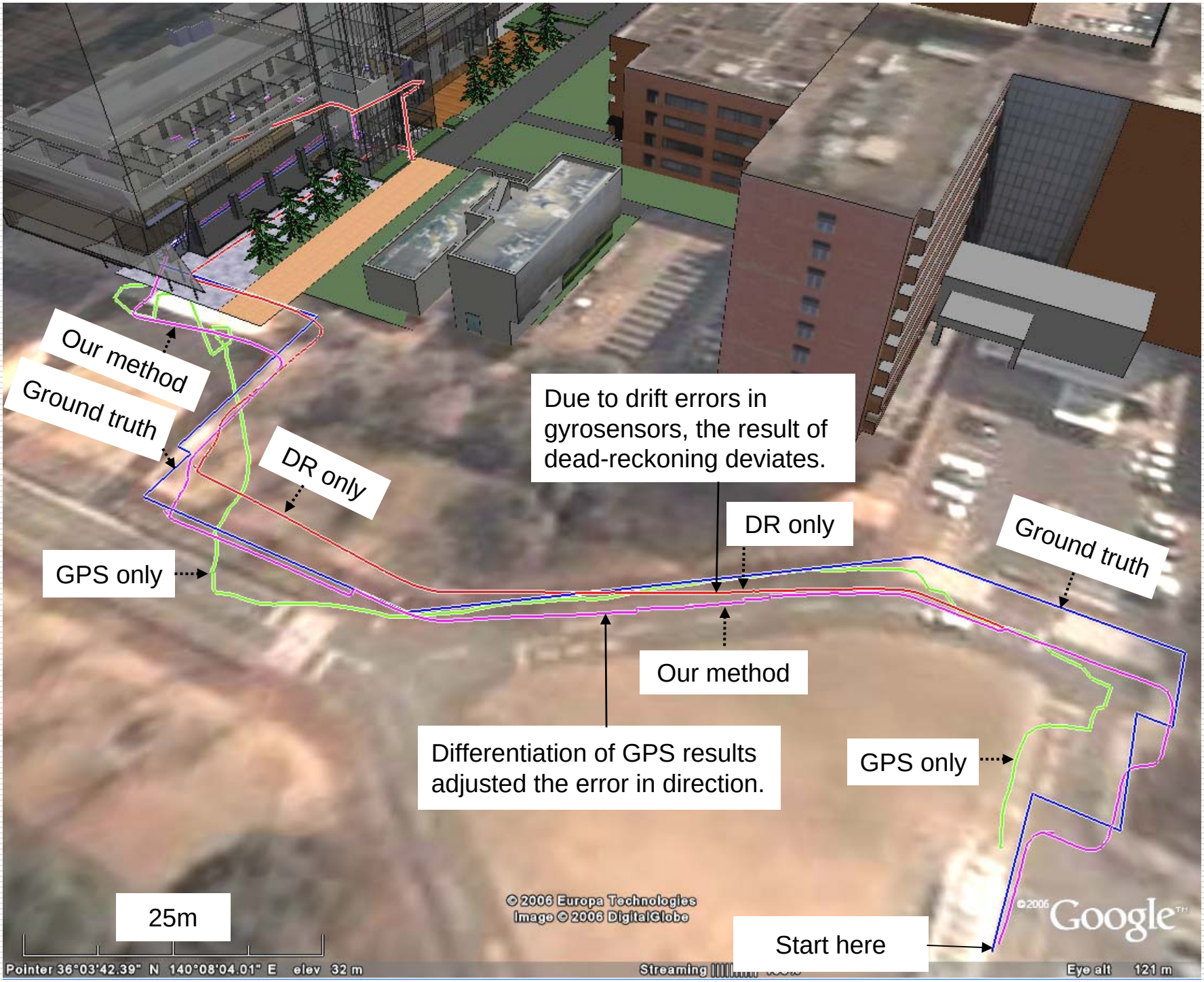


Demo video:
Our system in actions (Outdoors)



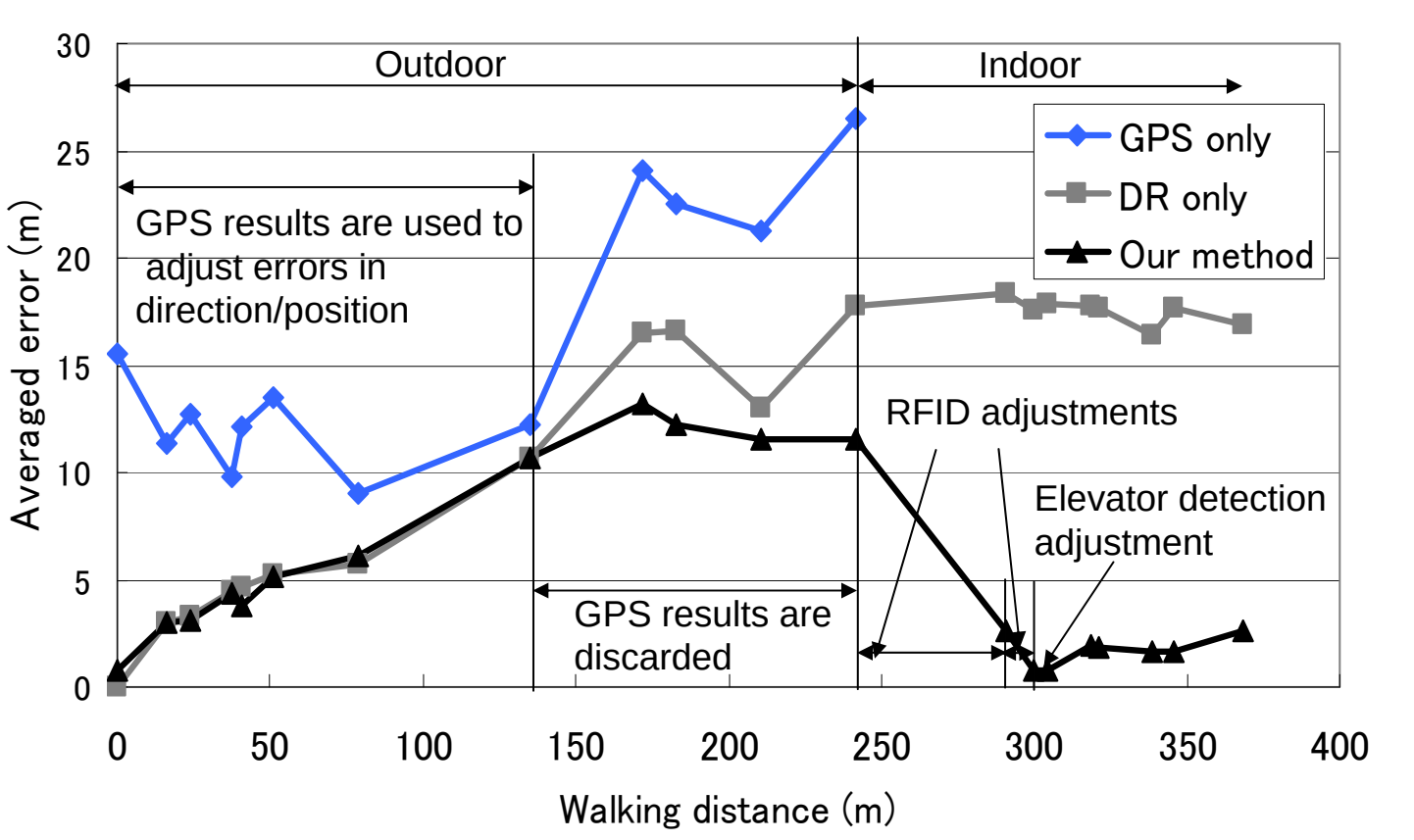
Experiments:
The ground truth vs estimation

- Setting for experiment:
  - 368.1 meter route (outdoor: 247.2 meter, indoor: 120.9 meter)
  - Two RFID readers are placed in the building to correct user's position.
  - Five subjects traveled along with the same route.
  - Estimations by the proposed method were compared to the ground truth of the route.


Our method
Ground truth
DR only
GPS only
Due to drift errors in gyrosensors, the result of dead-reckoning deviates.
DR only
Ground truth
Our method
Differentiation of GPS results adjusted the error in direction.
GPS only
25m
Start here
© 2006 Europa Technologies
Image © 2006 DigitalGlobe
Google
Pointer 36°03'42.39" N 140°08'04.01" E elev 32 m
Eye alt 121 m

Experiments:
The ground truth vs estimation

- Error graph along with walking distance



Practical usage of the system: Openhouse situation with kids

- 23 kids have experienced our prototype system.
  - No prior training or calibration is required.
  - User's height is only parameter required by the system.
  - The system worked well even if kids moved in unexpected manners.

Conclusion

- GPS/RFID/Dead-reckoning integrated positioning method is proposed.
- Embedded pedestrian navigation system is implemented with the proposed method.
- Accuracy of the proposed method is shown to be 5-10% of total walking distance.
- Kids can play with the system in the open house situation.