Indoor Localization in Public Buildings

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6th Annual AURA Workshop - Hanoi, Vietnam

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Location-based Services (LBS)

- **Information customization based on user location**
- **Navigation guide**
- **Location-based advertising**
- **Security surveillance, alert, notification, warning,…**
- **…**

Indoor Localization

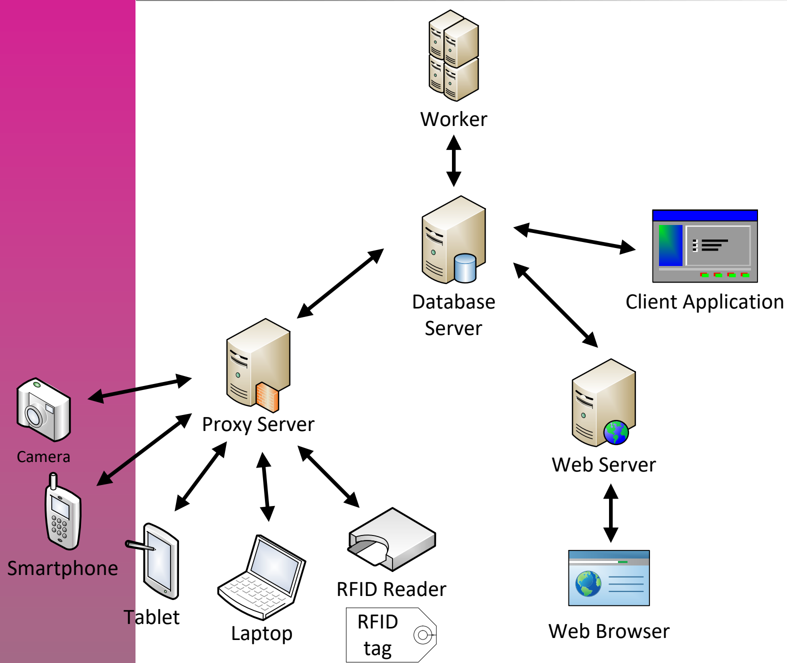
- **GPS generally works only outdoor ➔ search for indoor localization schemes**
- **Many approaches proposed for indoor localization: cellular networks, infrared, ultrasonic, computer vision, RFID…**
  - All suffer either from the limited accuracy, range, lacking of the infrastructure, or high deployment price

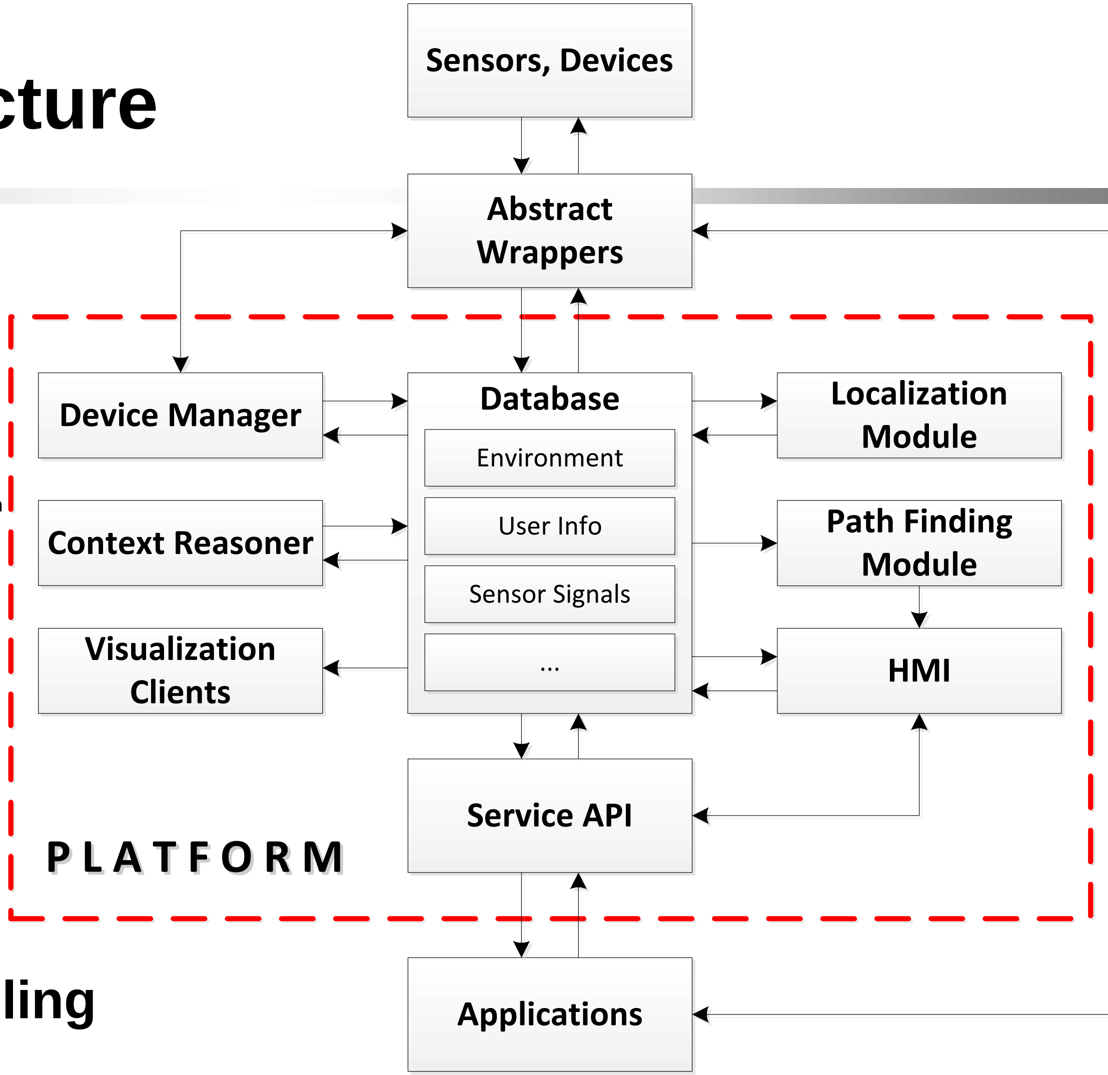
➔ Combination of multiple technologies to overcome the limitation of individual ones

Outline

- Introduction
- System architecture
- Localization in indoor environment
- Sample applications
- Conclusion

System Architecture

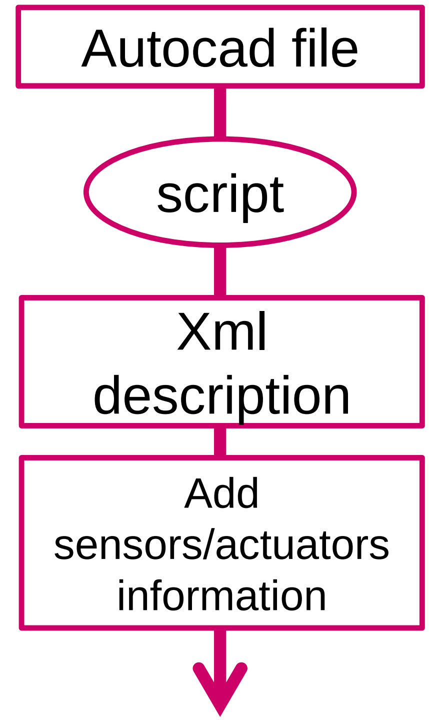




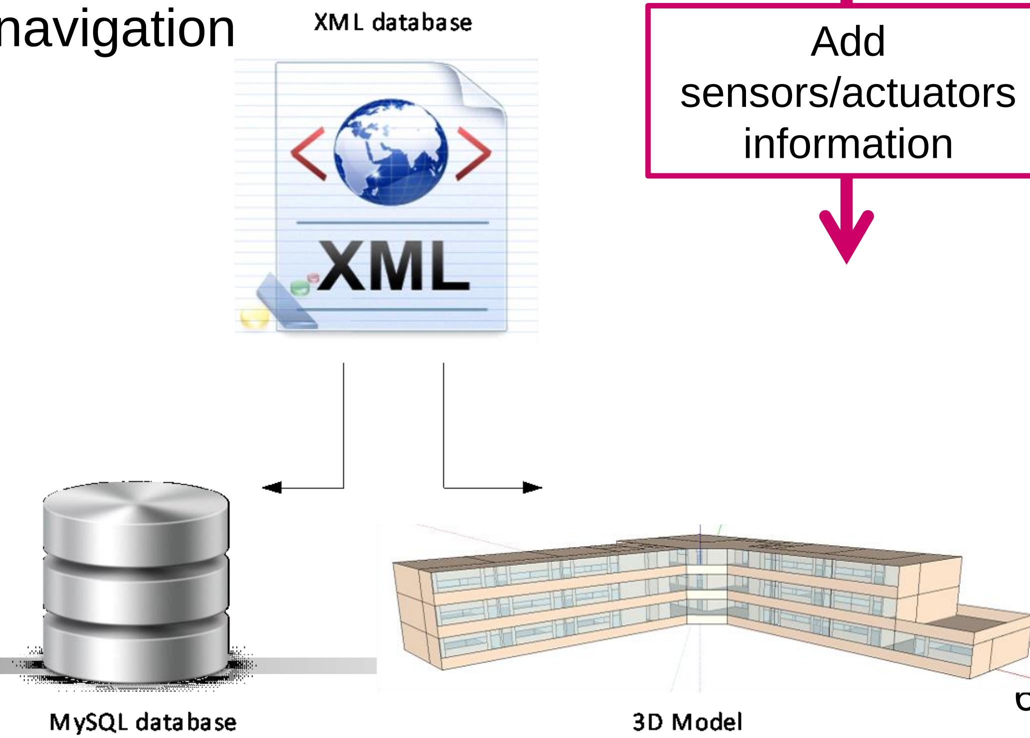
- Environment modeling
- Visualization
- User/robot localization, tracking & navigation
- Device management
- User information collection

Environment Modeling

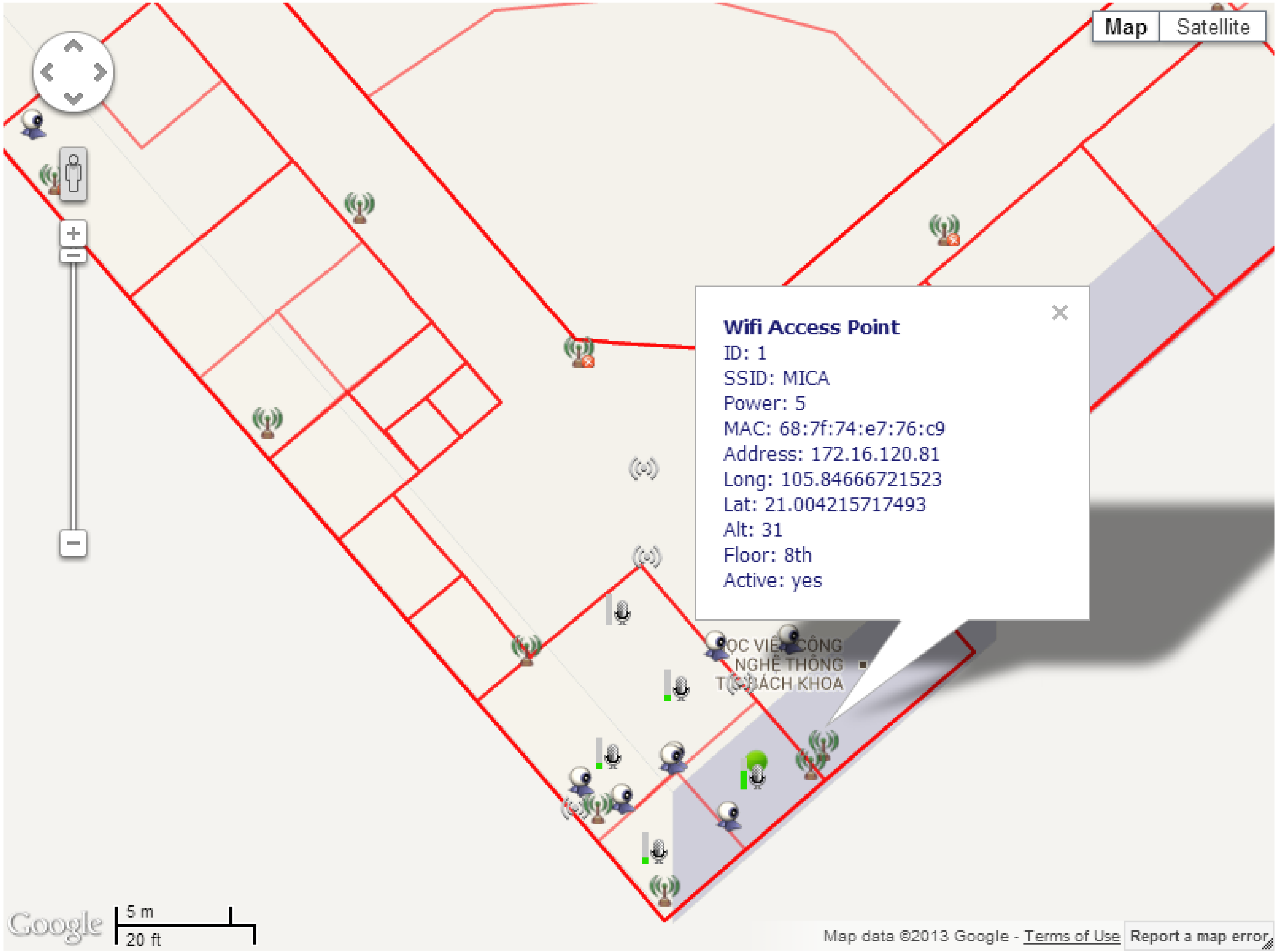
- **Unified environment model for**
  - Localization
    - Signal attenuation for WiFi, RFID,…
    - Range information for cameras
    - Result validation
    - Result filter with map information
  - Path-finding and navigation
  - Visualization



- **Using XML**



Visualization using Google Maps (2D)



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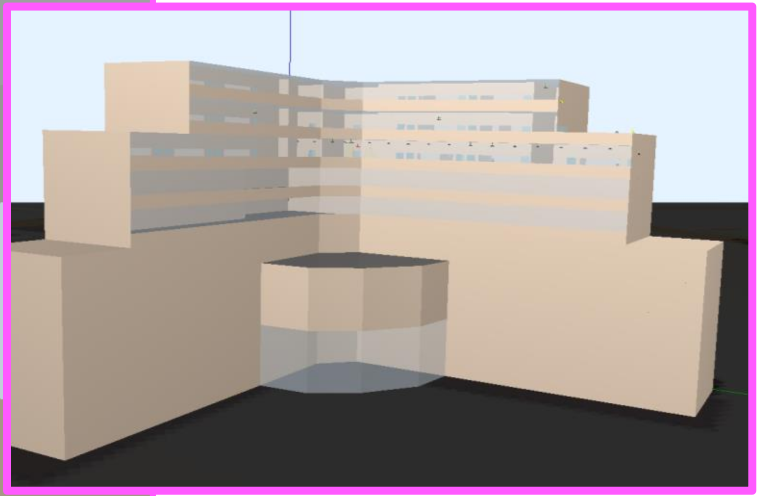
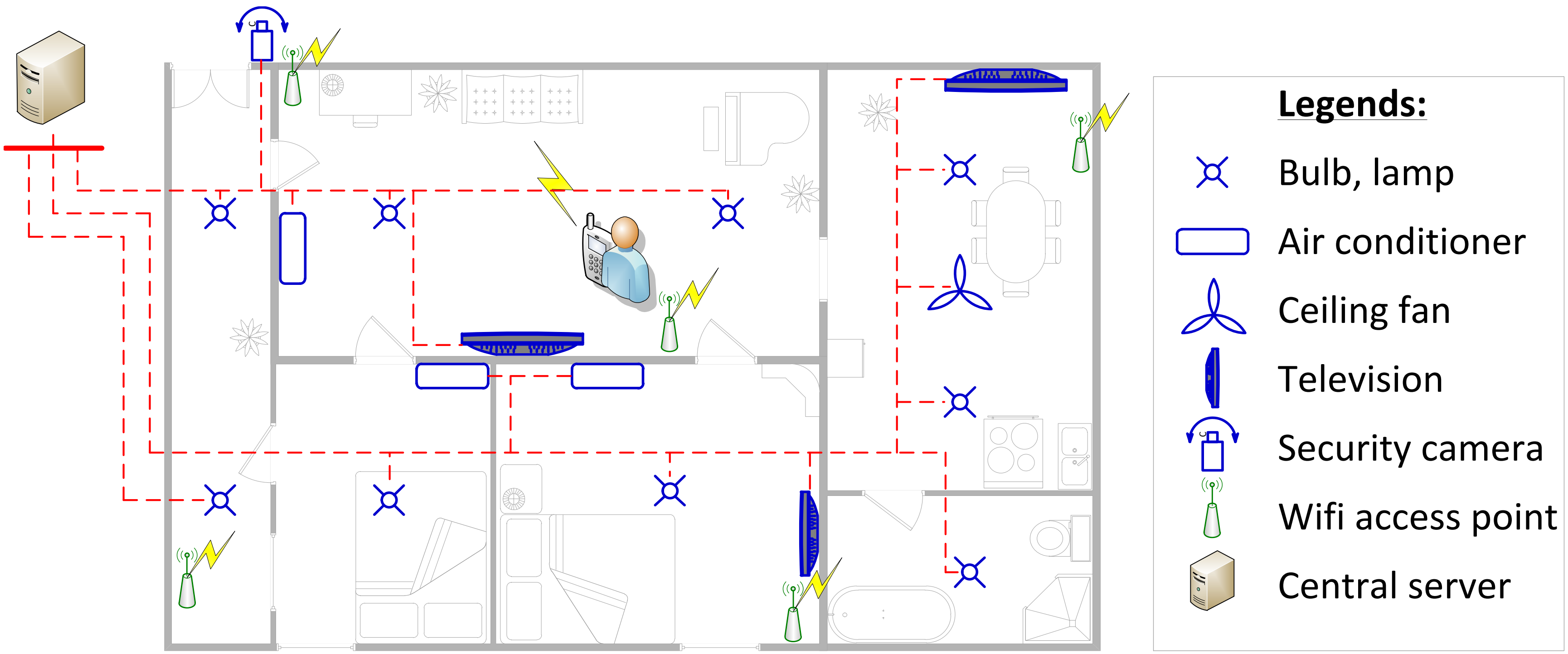
Visualization using Standalone App (3D)



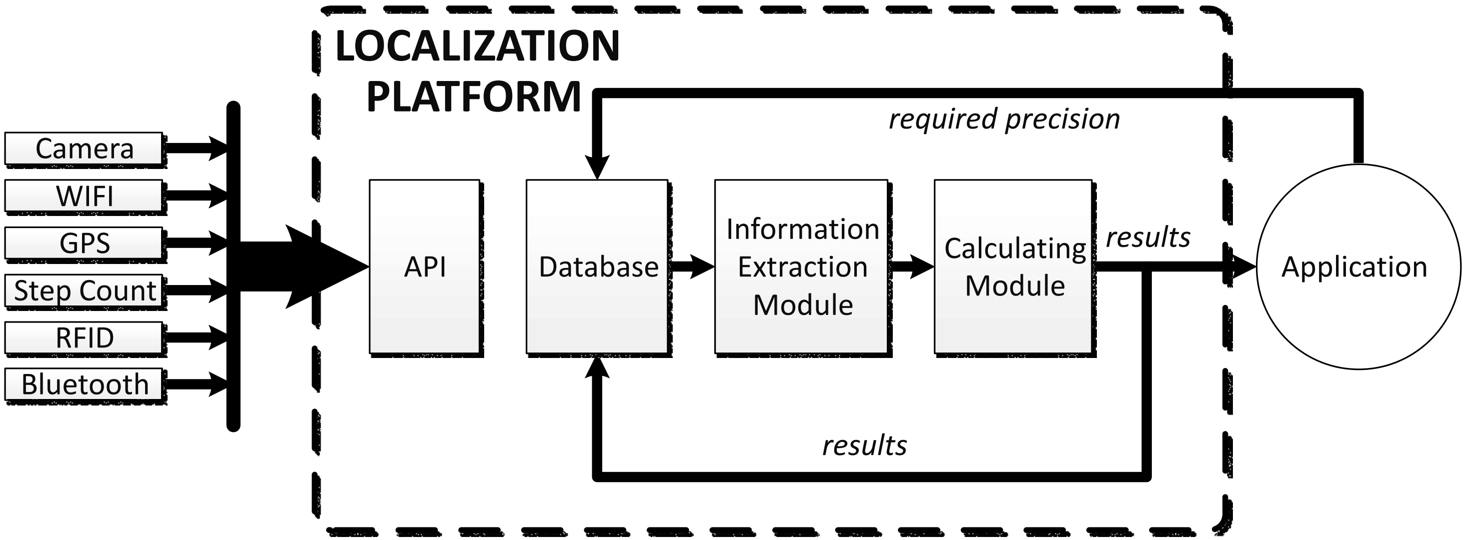
Device Management

- **Abstract layer for devices**
- **Allowing 2 modes**
  - Physical mode with real devices
  - Simulation mode with virtual devices



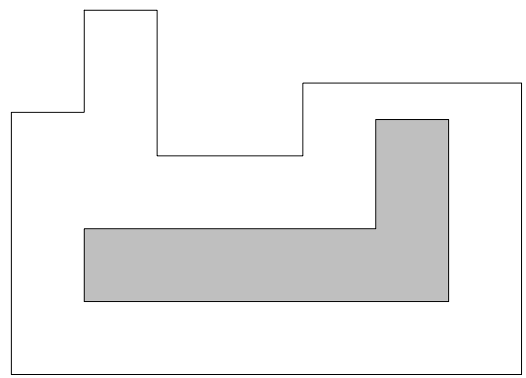
User/Object Localization

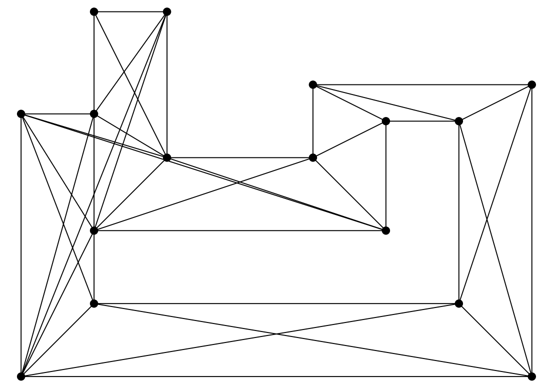
- **Integration of multiple technologies**
  - WiFi signals
  - RFID
  - Cameras
  - Bluetooth
  - Step count
  - Multimodal (combination of above technologies)

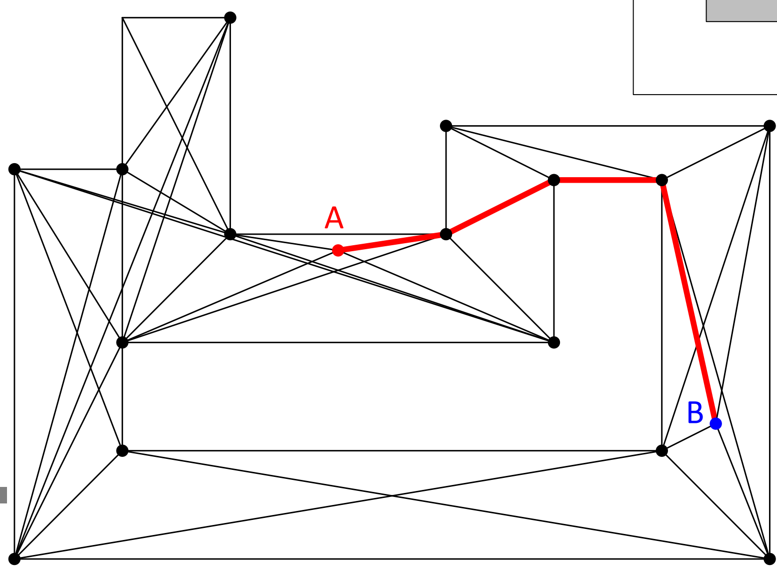


User/Robot Navigation

- **Optimal path finding**
  - Shortest path
  - Aware of walls, floors, stairs,…
  - Personalized on the basis of user context
  - Collision avoidance in dynamic environments

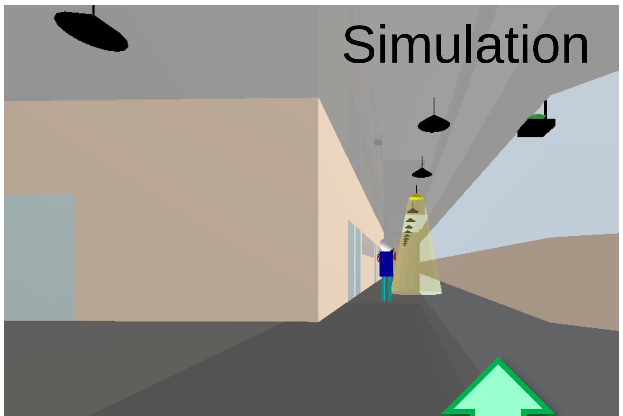




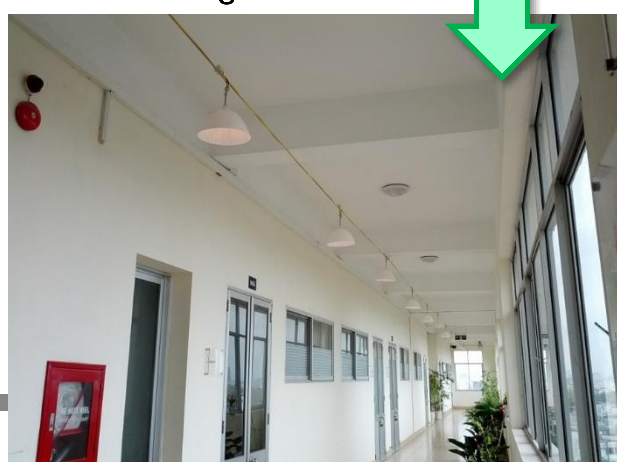


Technological Platform

- **Validation by**
  - Virtual reality simulation
  - Physical platform



MICA building



- **Generic modelling**
  - It is easy to build models for différent buildings

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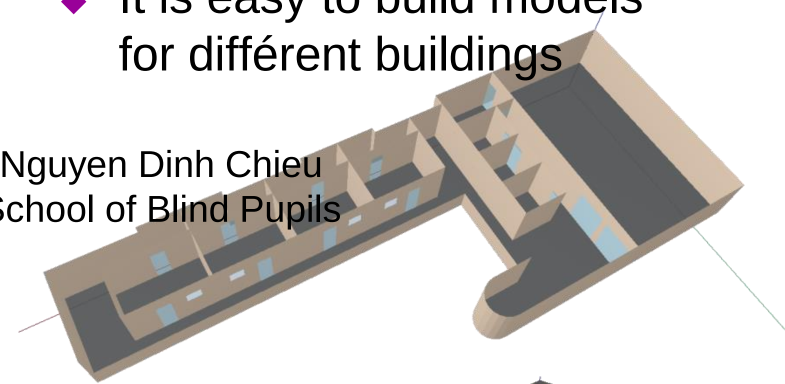
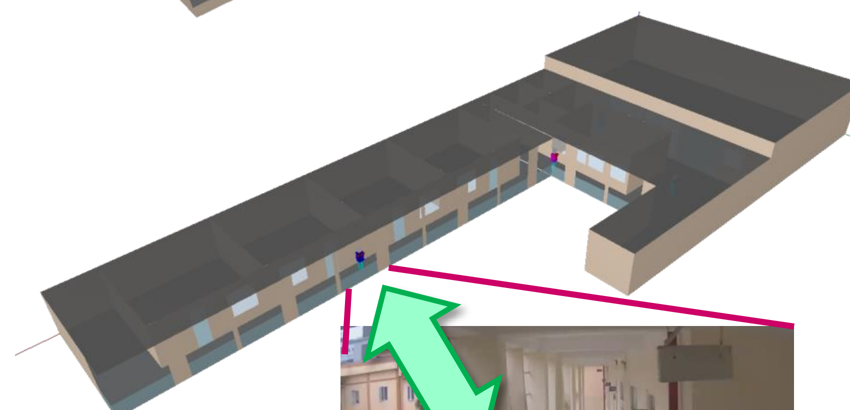
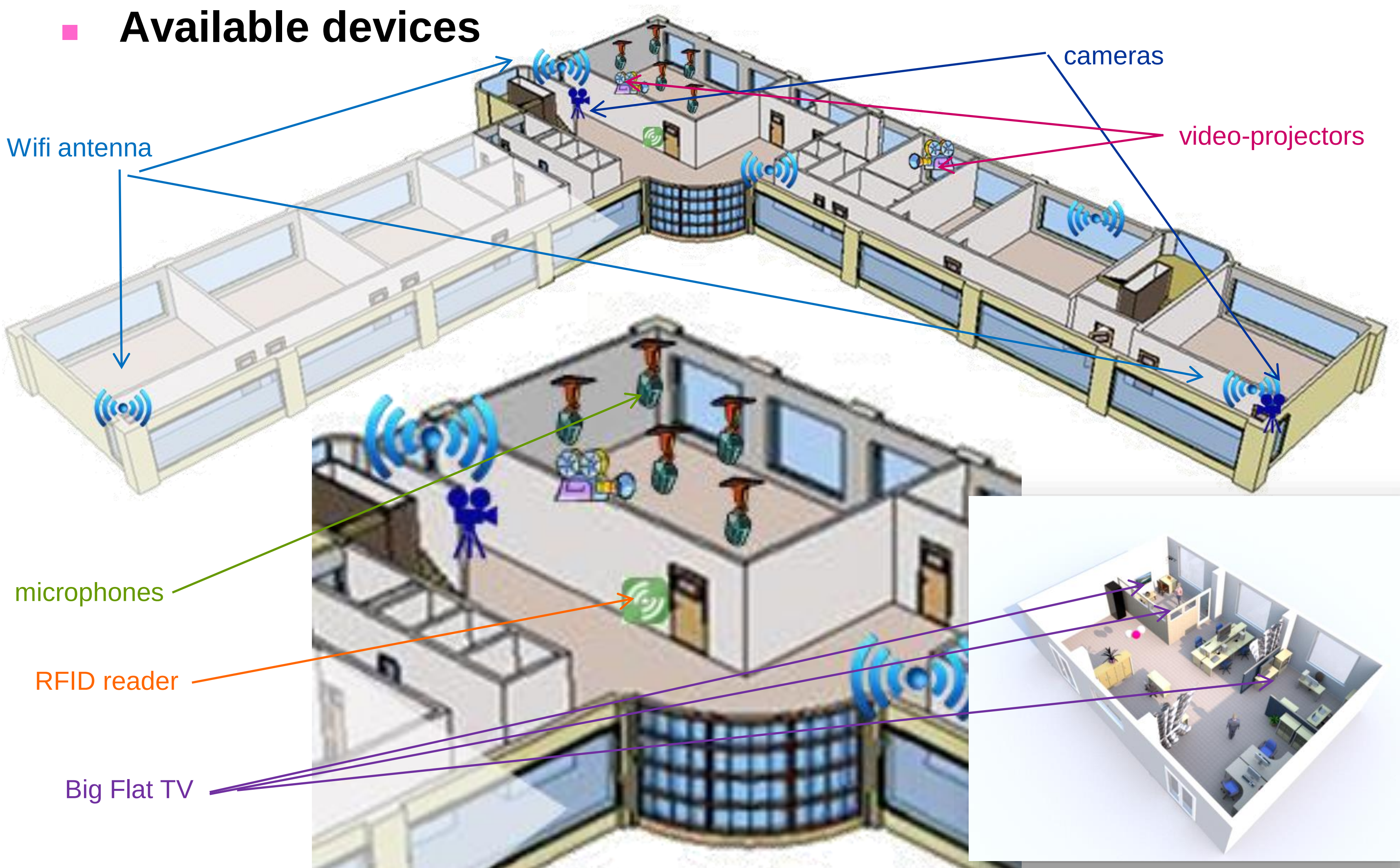
School of Blind Pupils





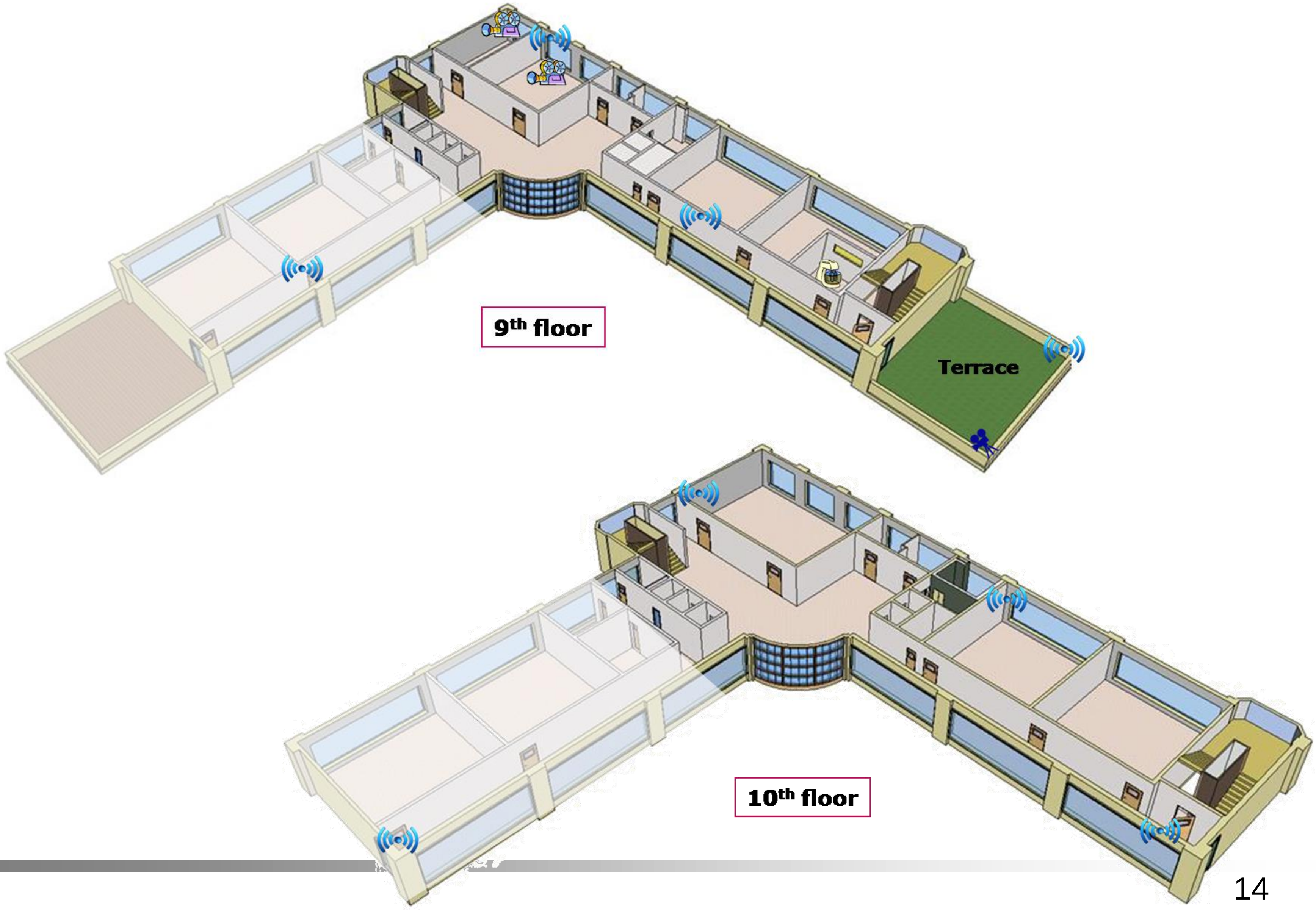
Technological Platform
8th floor

- **Available devices**



Technological Platform

9th and 10th floors



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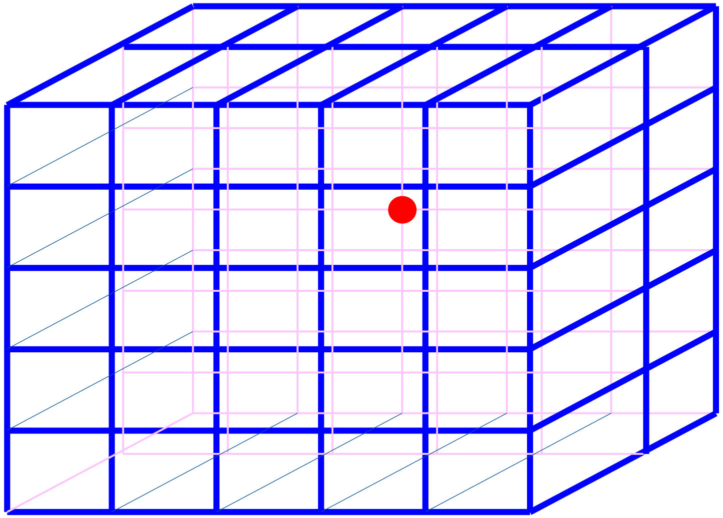
Aggregation Approach

- **Probability based**
  - For each point (x,y,z), calculate aggregation probability ρ_Σ
  - Choose (x,y,z) with highest ρ_Σ and acceptable precision

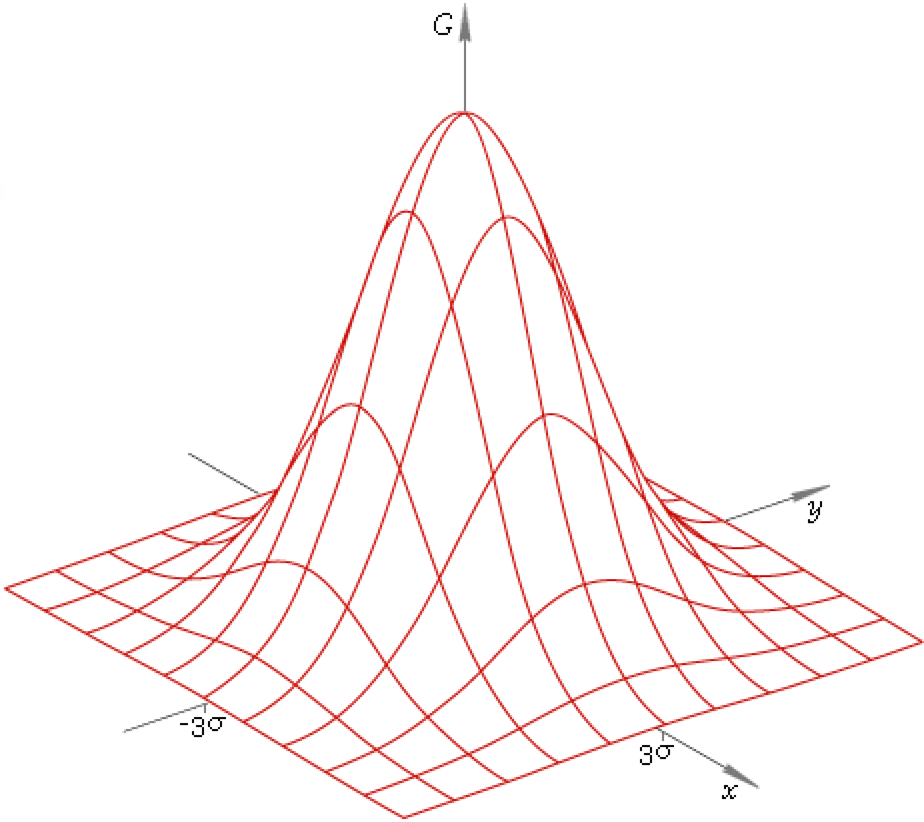


- **Maximizing**

$$\rho_\Sigma(x,y,z) = \underset{i=1..n}{\Omega}\left(\rho_i(x,y,z)e^{-\lambda_i t}, R_i\right)$$

  - Ω: probability aggregation function (sum, product,…)
  - n: number of technologies
  - ρ_i: probability of technology i
  - R_i: precision constant of technology i
  - λ_i: time decay constant of technology i

GPS



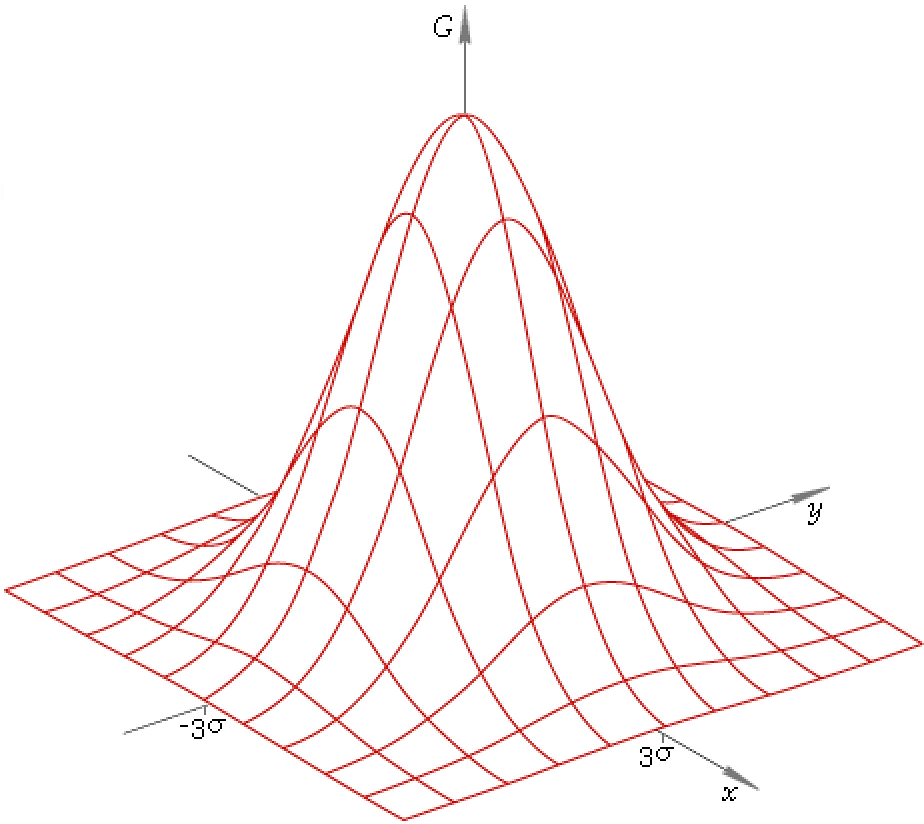
- **Gaussian probability**

$$\rho_i(x,y,z)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}{2\sigma^2}}$$

  - (x_0,y_0,z_0): returned location by GPS
  - σ: function of accuracy by 3-sigma rule

RFID

- **Fixed reader**



- **Gaussian probability**

$$\rho_i(x,y,z) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}{2\sigma^2}}$$

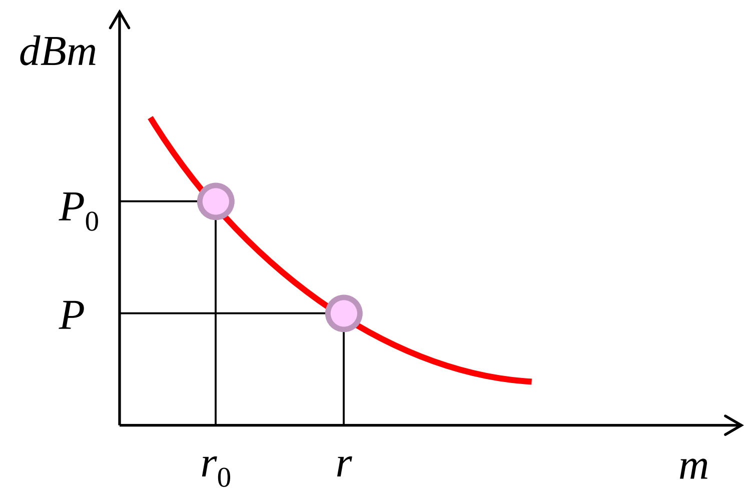
  - (x_0, y_0, z_0): reader location
  - σ: function of reader range by 3-sigma rule

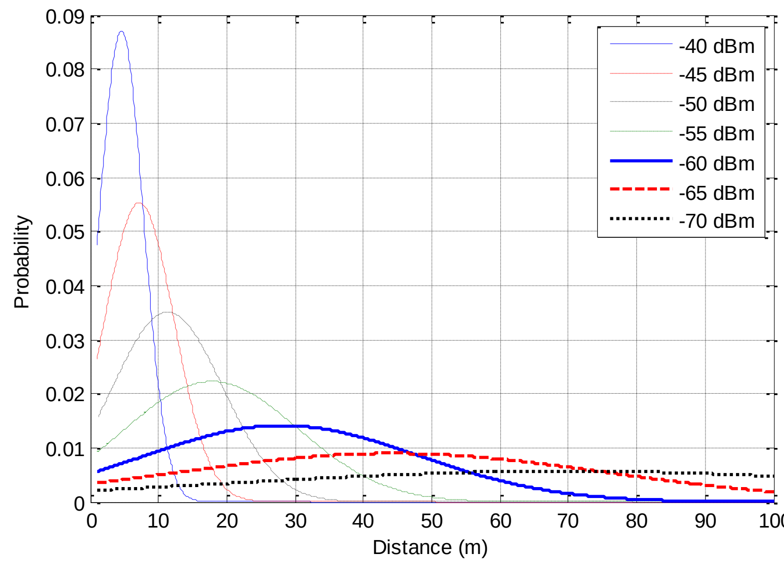
WiFi

- **Gaussian probability**

$$\rho = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(r-r_0)^2}{2\sigma^2}}$$

  - r_0: nominal distance from empirical propagation model
  - σ: function of r_0

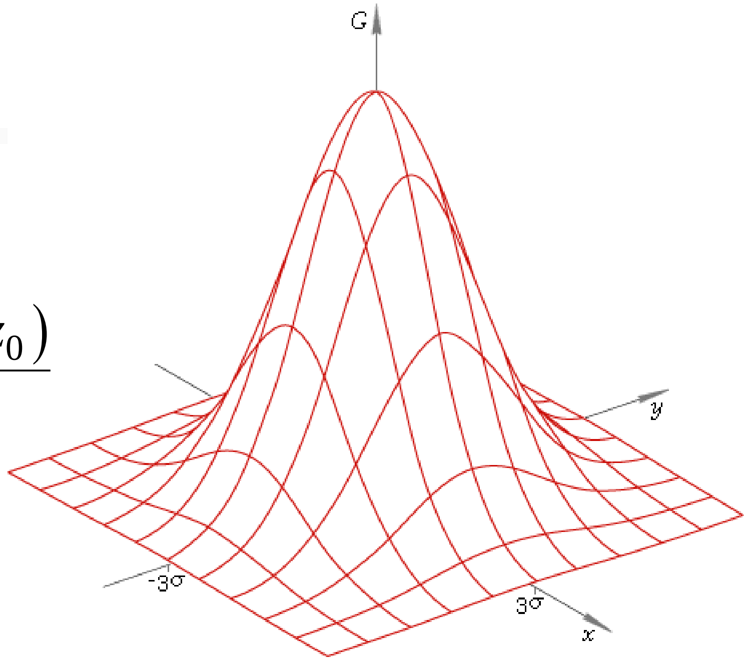




Pedometer

- **Gaussian probability**

$$\rho_i\left(x,y,z\right)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{d^2\left(x,y,z,x_0,y_0,z_0\right)}{2\sigma^2}}$$

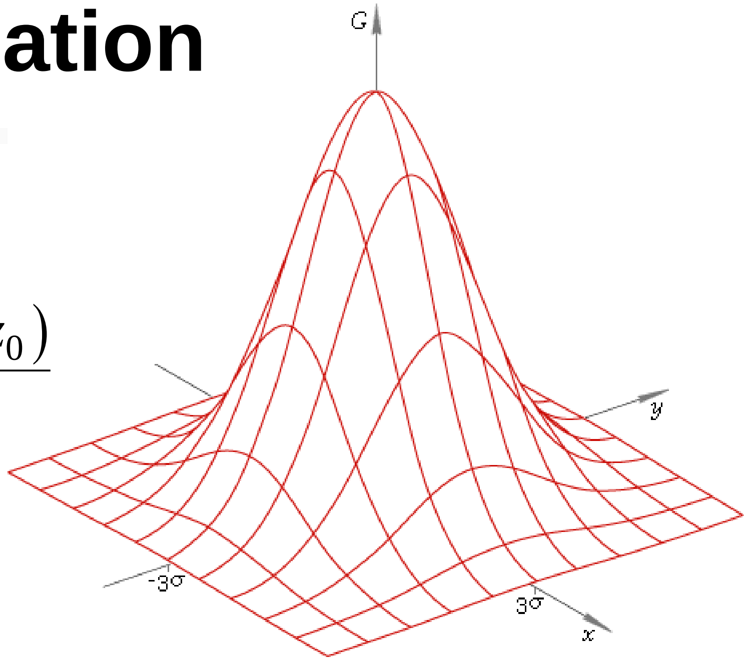


- (x_0,y_0,z_0): nominal user location
- σ: function of (*step-length x step-count*) and history precision
- d: Euclidean distance function

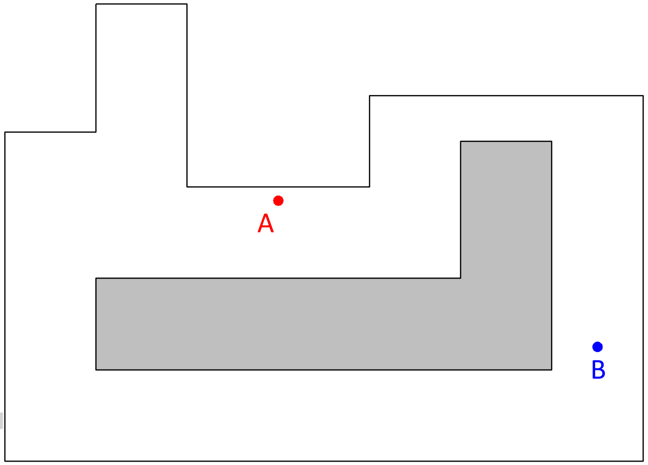
Historical & Map Information

- **Gaussian probability**

$$\rho_i(x,y,z) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{d^2(x,y,z,x_0,y_0,z_0)}{2\sigma^2}}$$



- (x_0,y_0,z_0): previous user location
- σ: function of user speed by 3-sigma rule
- d: distance function with environment map awareness
  - Shortest-path based
  - Impossible location avoidance



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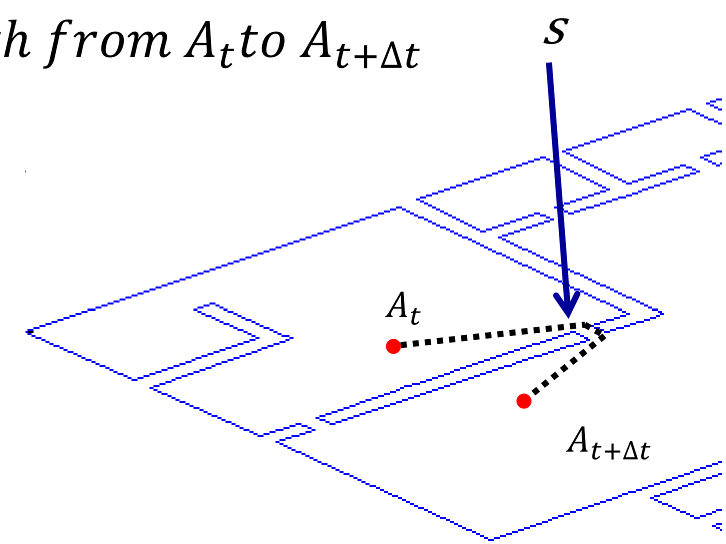
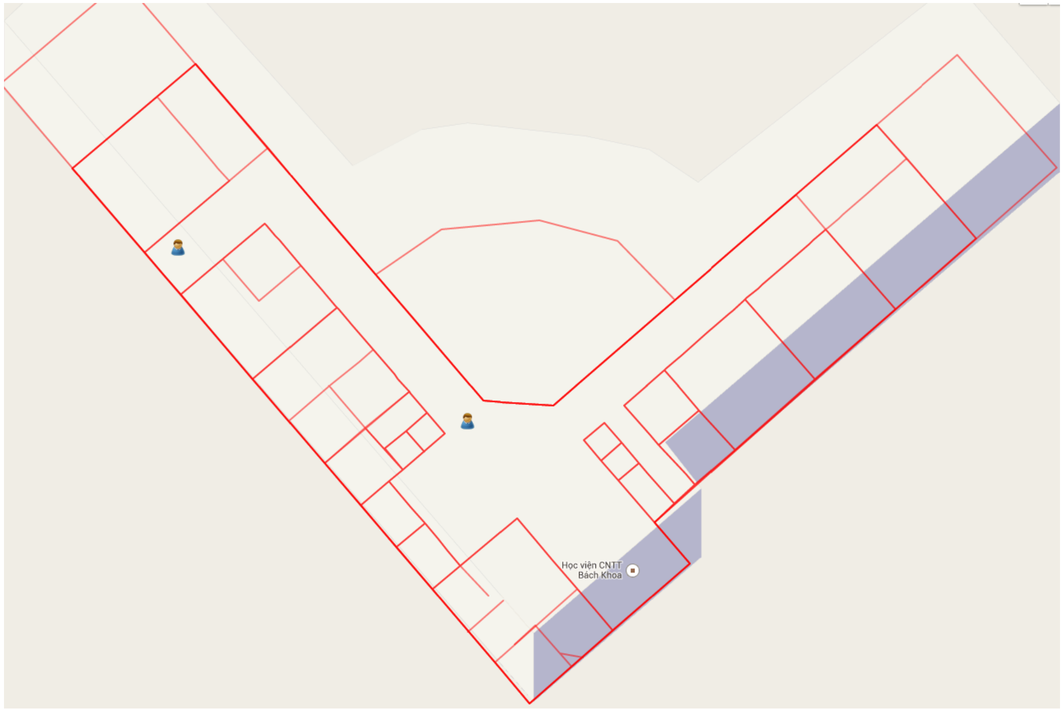
Enhancement with Environment Constraints

- **Speed constrain**
  - Localization results are convergence with some error especially for points near walls.
  - $s^* = v \times \Delta t$
    - $s^*: distance\ traveled\ in\ \Delta t\ with\ average\ speed\ of\ user\ is\ v$
    - $\Delta t: time\ difference\ between\ 2\ localization\ results$
  - $s: shortest\ walkable\ path\ from\ A_t to\ A_{t+\Delta t}$
  - $Constrain: s^* < s$



Results

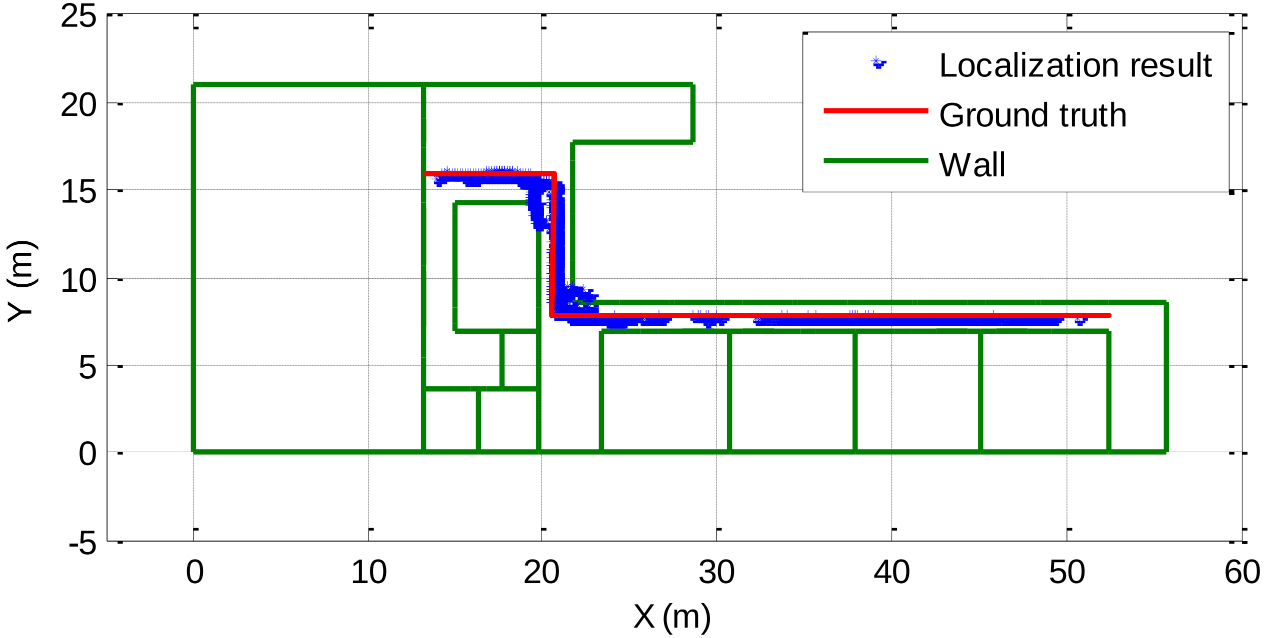
- **WiFi only:**
  - video
- **WiFi + RFID + pedometer:**
  - video
- **WiFi + RFID + pedometer + historical & environment info:**
  - video

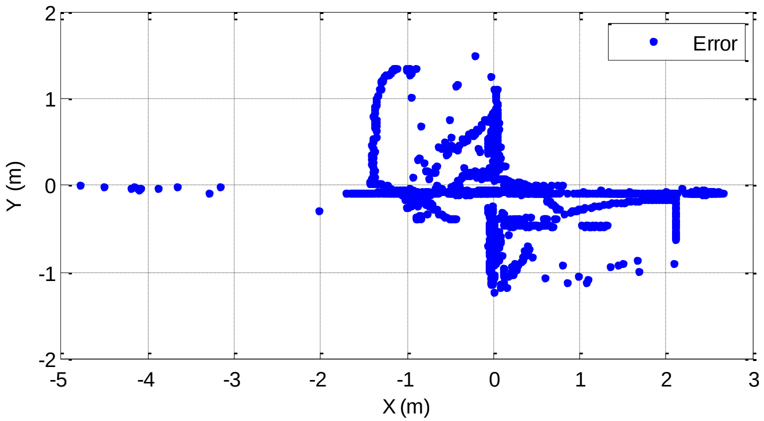


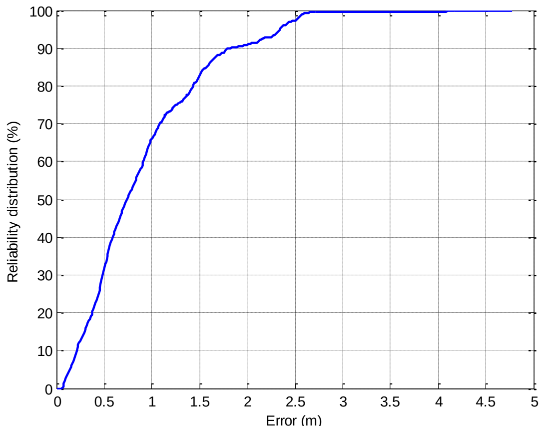
Results

	WiFi, no constrains	WiFi, with constrains	Cam, no constrains	Cam, with constrains	Multi, no constrains	Multi, with constrains
Data samples	129	129	1833	1833	1966	1966
Max error (m)	7.63	4.48	4.53	4.50	4.78	4.79
Average error (m)	1.66	1.55	0.88	0.88	0.91	0.89
Std. deviation(m)	1.16	1.30	0.64	0.64	0.67	0.65
RMSE (m)	2.19	1.91	1.09	1.09	1.13	1.10
Error with reliability of 90% (m)	3.26	3.17	1.69	1.69	1.83	1.71

Results: Multimodal, with Constrains







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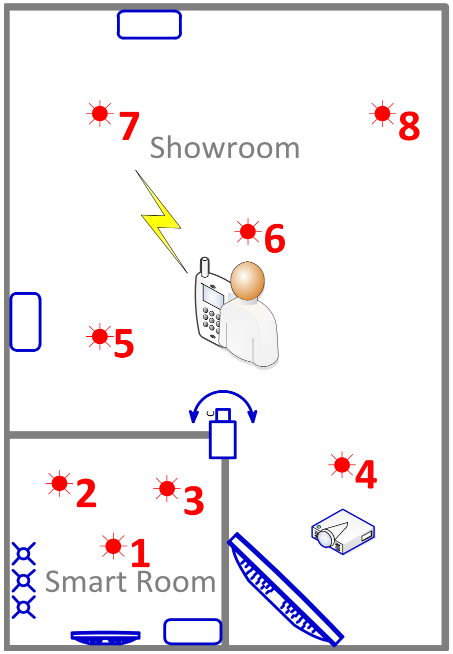
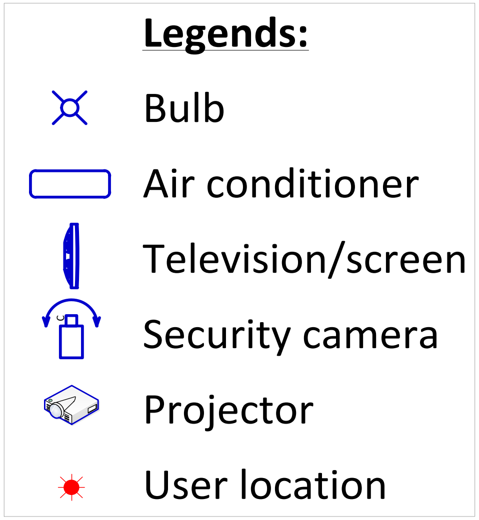
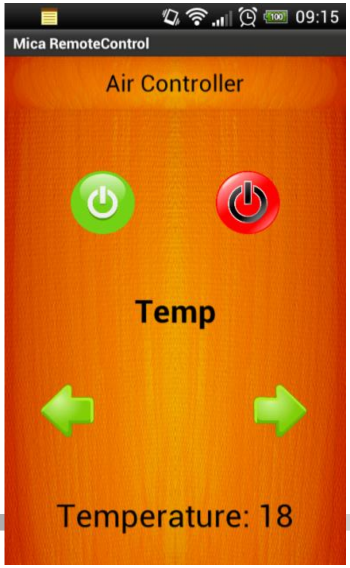
Smart Remote Control for Home Appliances

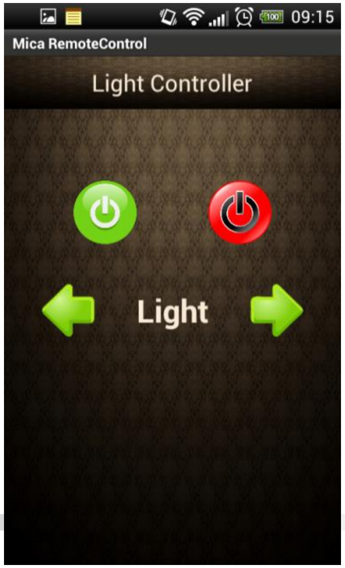




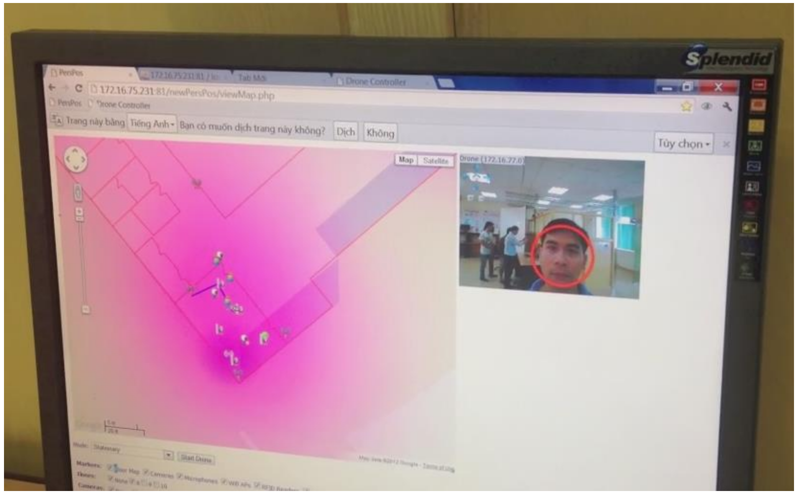
- **Based on**
  - User location
  - Phone orientation

- **Tilt angle tolerance: 15°**
- **1 television, 1 projector, 3 air conditioners, 3 bulbs, 1 security camera**
- **Showroom (9 m×13.5 m) + Smart-room (4.5 m×4.5 m)**
- **Tested at 8 different locations**





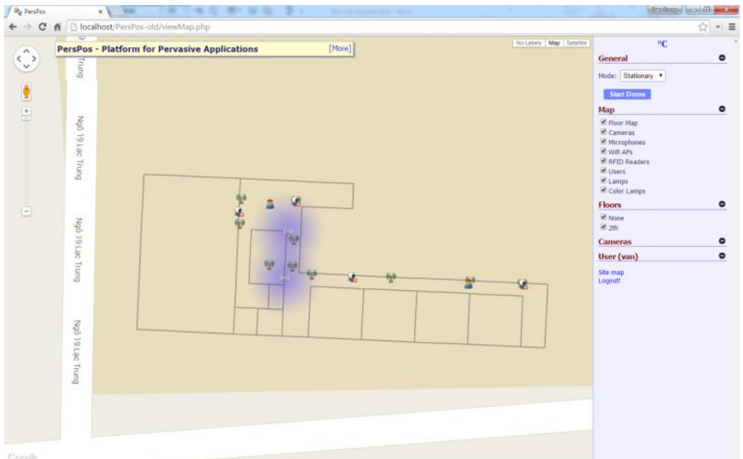
Interaction with Robots

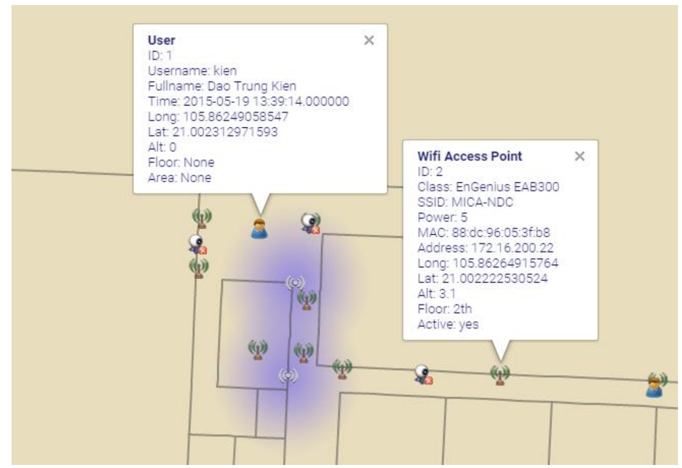


User-Adaptive Device Control

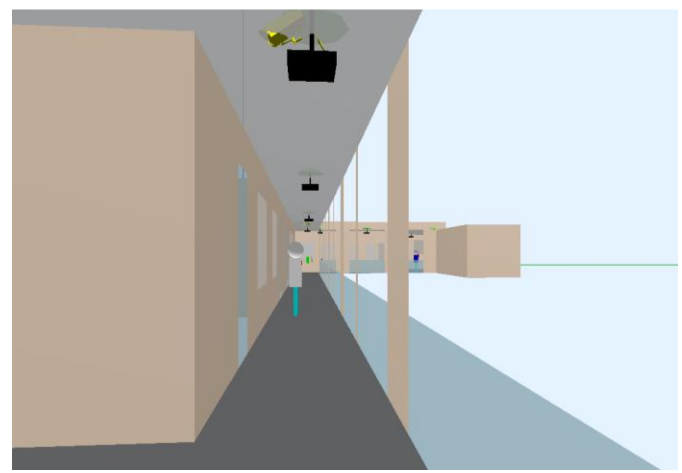
Nguyen Dinh Chieu School for Visually Impaired People

- 2D map

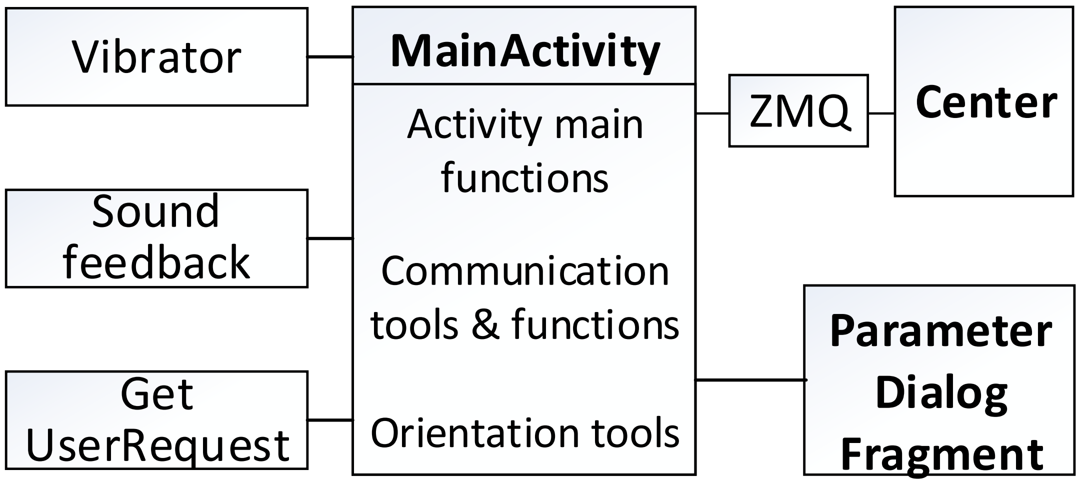




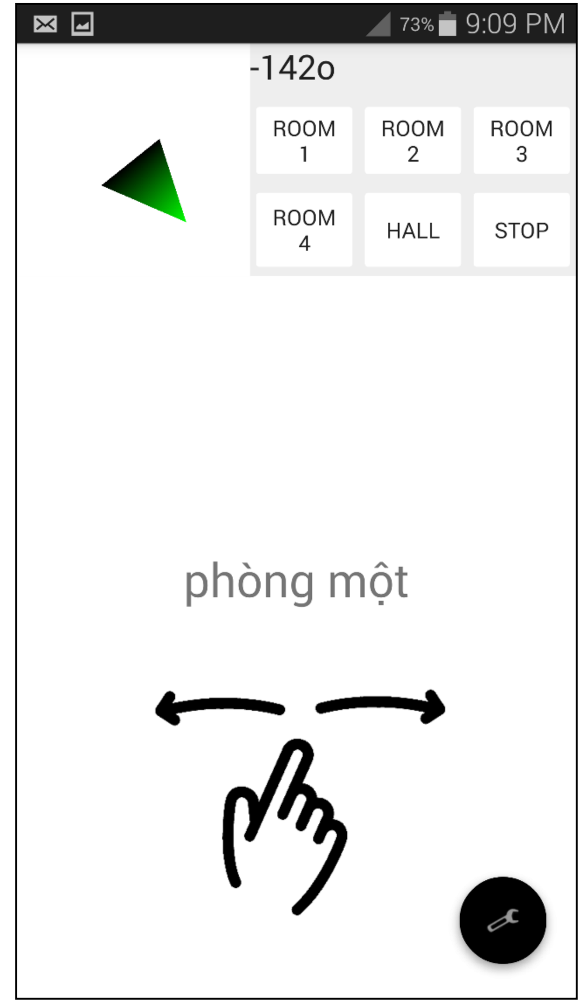
- 3D view



User Interaction via Smartphone



Interaction module



App interface

Guidance for Visually Impaired People

>> Video

Conclusion

- **Platform for the development of pervasive computing applications**
- **Highly extensible with generic design and implementation**
  - Heterogeneous devices and generic data management
  - Integration of multiple technologies for localization and navigation
- **Object-oriented modeling of dynamic environments**
- **Real-time visualization, and service provider for applications**

Thank you

for your attention!