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Geomagnetic Field Based Indoor Localization Using Recurrent Neural Network

2018 SURF Project

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Speaker: Xiangxing. Li (Carlos)

Zhengxing. Zhong (Klaus)

Outline

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  - *K Nearest Neighbor (KNN)*

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- *Data Generation for Training*

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- *Experiment results*

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Project introduction

■ Motivation

- *Commercial interests and demand for indoor localization increases.*

- *RF signal-based systems are the most common due to convenience and cost saving.*

- *However, the unstable nature of RF signals limited the accuracy of RF-based indoor localization.*

Project introduction

■ Overview

1. *Build a geomagnetic map (as well as BLE fingerprinting map).*

2. *Generate 50,000 traces of various pedestrian walking pattern from the map by Linear Interpolation algorithm.*

3. Use Google Tensorflow with NVIDIA cuDNN library as a Deep Learning framework. 95% of the traces are used for training and 5% (2500) of the traces are used for localization evaluation.

4. Result: Average positioning error of 1.062 meters compared to the average error of 3.14 meters of our BLE (Blue Tooth Low Energy) fingerprinting results.

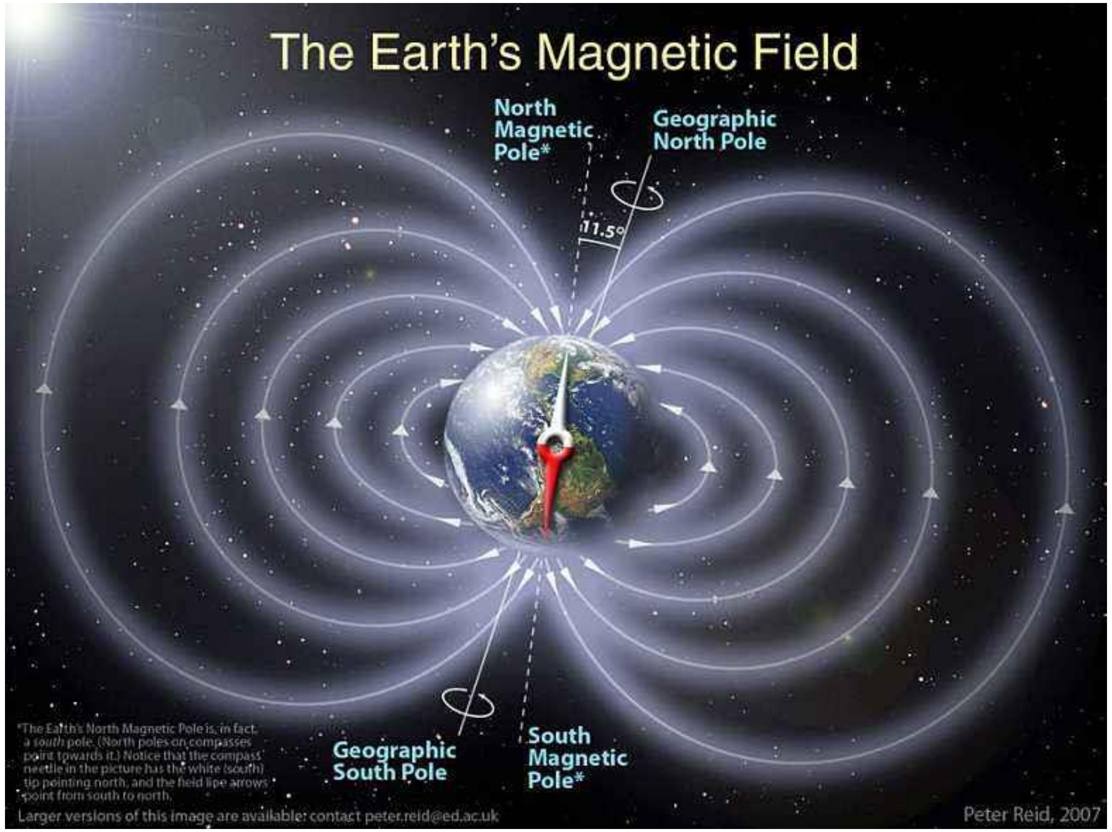
Method background

- *Geomagnetic filed*
- *Indoor positioning techniques*
  - K Nearest Neighbor (KNN)

Geomagnetic filed

■ Geomagnetic field

Centrosphere produces the magnetic field that extends from the Earth's interior out into space.

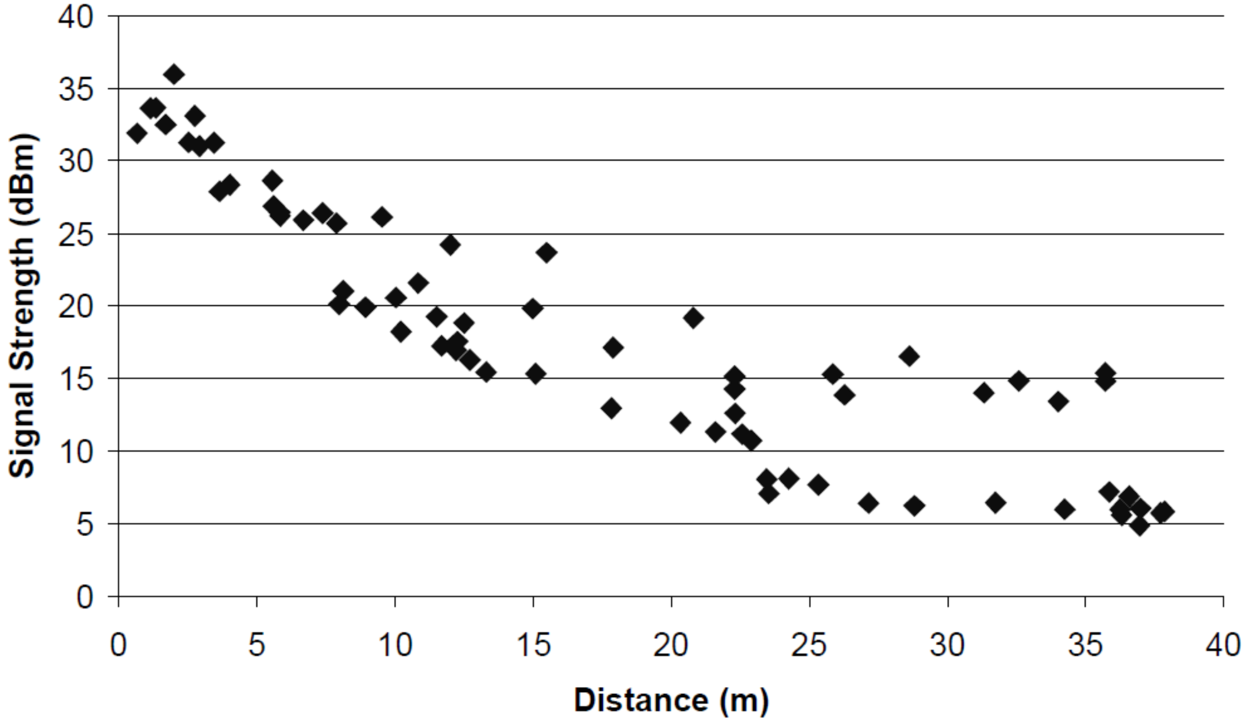


GM filed based vs. RF signal-based localization

- RF signal based localization

Unstable nature caused by interference, diffraction, and reflection in indoor environment.

In indoor environment, the signal strength varies as the it gets further away from the ratio transmitter terminal.



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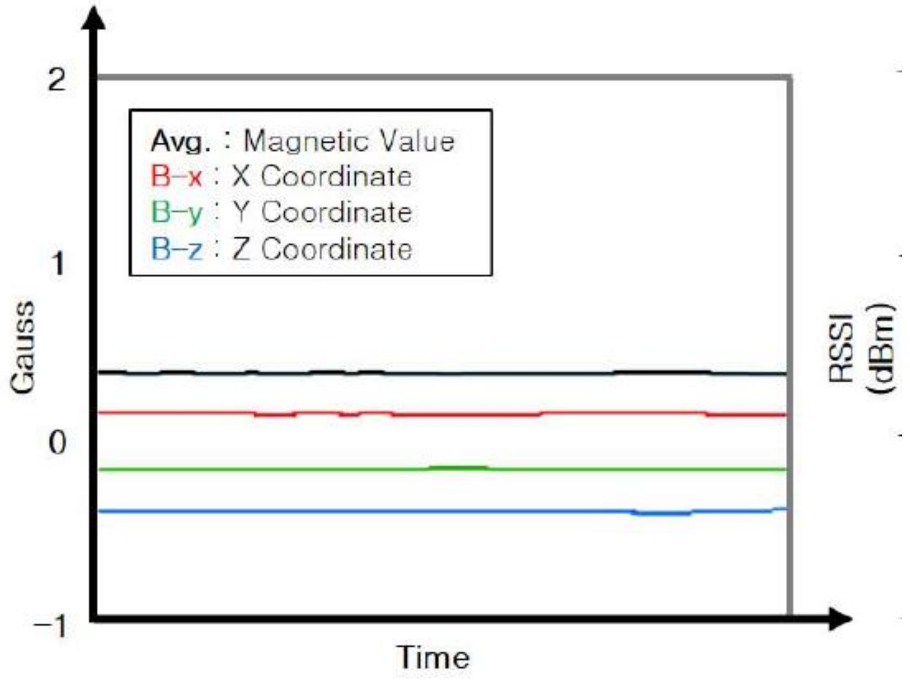
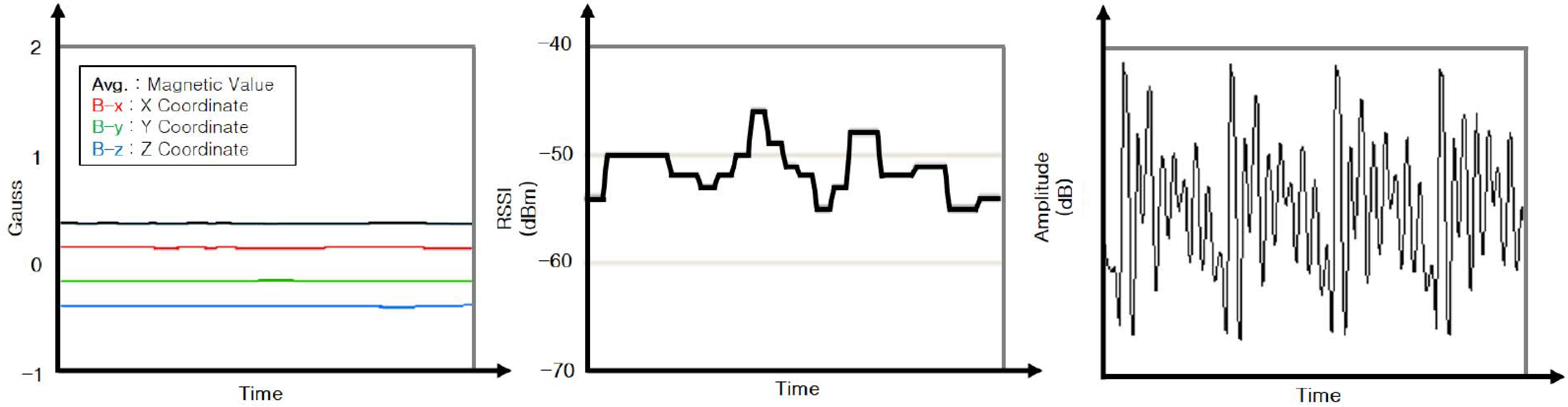
GM filed based vs. RF signal-based localization

■ GM filed based localization

The geomagnetic field is influenced by metal, thus the fixed space owns its specific geomagnetic field.



GM filed based vs. RF signal-based localization



Measurements of geomagnetic field, wireless LAN, and sound waves according to time

Geomagnetic filed

■ Detection

Working principle:
Hall Effect

Device:
Smart phone magnetic field sensors;
Standalone magnetic field sensors.

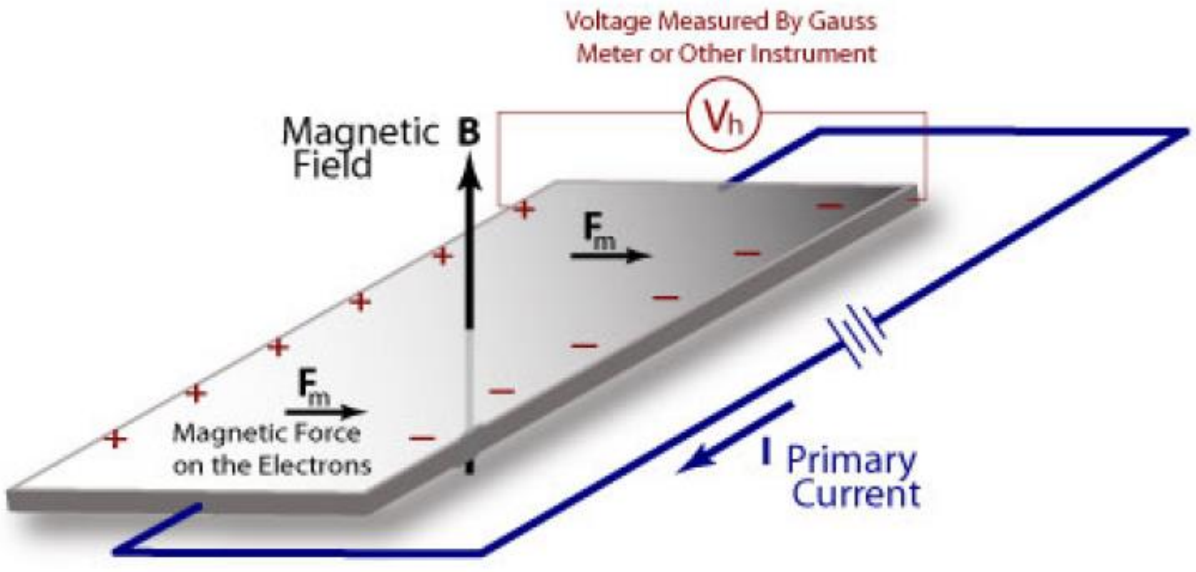


Fig. 4. Geomagnetic Hall Effect [19]

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Geomagnetic filed map

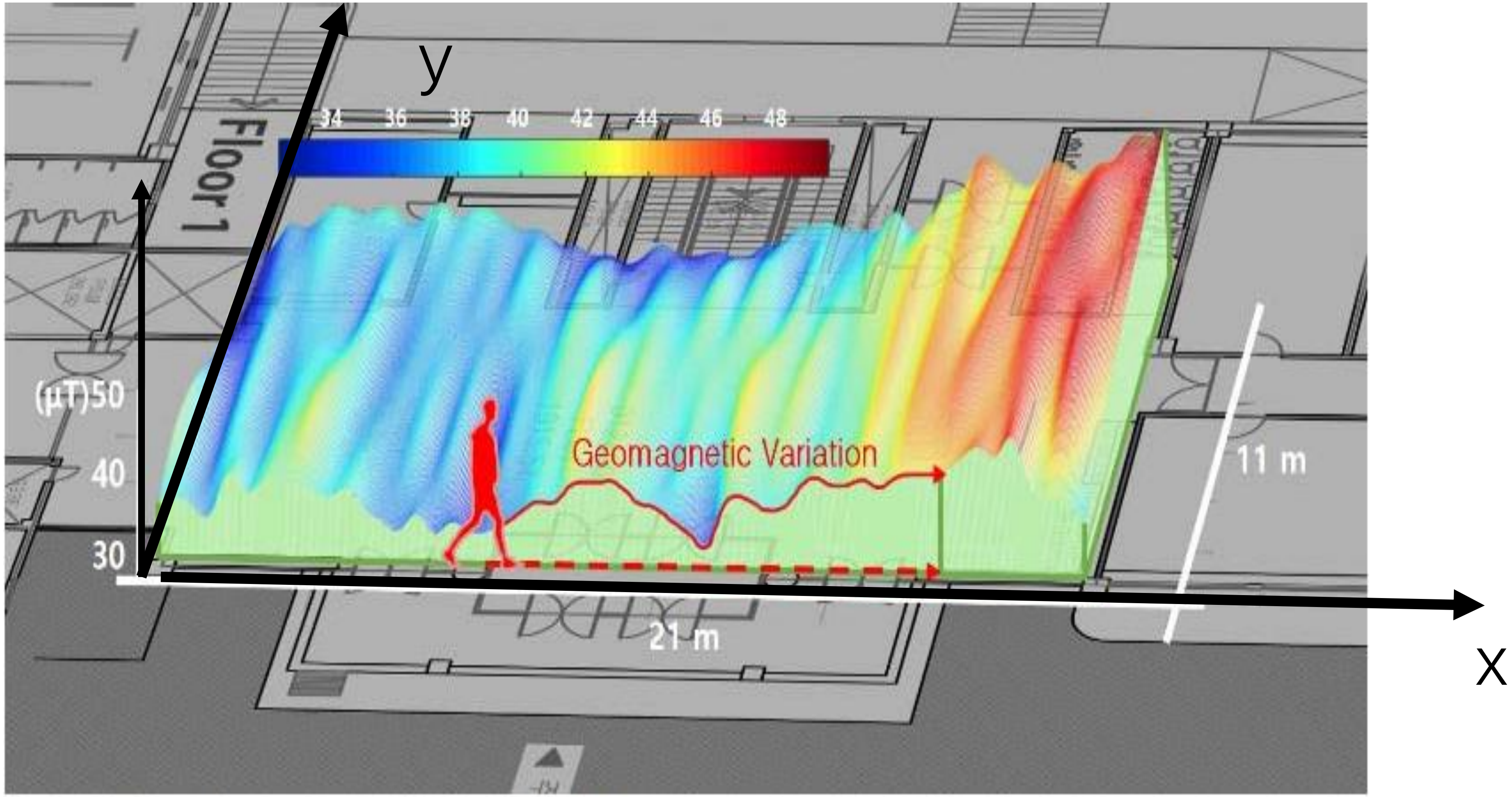

Fig. 3. Geomagnetic field variation according to movement

Indoor positioning techniques

- Absolute positioning

The estimated location is only derived from the current signal strength. (CNN)

- Relative positioning

It calculates the next position relative to the current position, which leads to incremental and contiguous location tracking. (RNN)

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KNN algorithm

- *The method for classification and regression*

By computing the Euclidean distance among the values with K-NN (Nearest Neighbor) algorithm, it finds the closest K neighbors and estimates the location that is actually the weighted center of those K neighbors.

*In Cartesian coordinates, if **p** = (p_1, p_2,..., p_n) and **q** = (q_1, q_2,..., q_n) are two points in Euclidean n-space, then the distance (d) from **p** to **q** is given by*

$$d(\mathbf{p},\mathbf{q}) = d(\mathbf{q},\mathbf{p}) = \sqrt{(q_1-p_1)^2 + (q_2-p_2)^2 + \cdots + (q_n-p_n)^2}$$

$$= \sqrt{\sum_{i=1}^{n}(q_i-p_i)^2}.$$

KNN algorithm

■ *Application in this project*

For KNN regression, whose labels are X-Y coordinates. The output is derived by averaging K coordinates.

Reference point location		
(1,3)	(2,3)	(3,3)
(1,2)	(2,2)	(3,2)
(1,1)	(2,1)	(3,1)

Reference point Geomagnetic strength		
12	24	6
48	33	26
42	18	38

KNN algorithm

■ *Application in this project*

For KNN regression, whose labels are X-Y coordinates. The output is derived by averaging K coordinates.

eg:
If detected geomagnetic field value is 25.
K = 2, location (2.5, 2.5);

Reference point location		
(1,3)	(2,3)	(3,3)
(1,2)	(2,2)	(3,2)
(1,1)	(2,1)	(3,1)

Reference point Geomagnetic strength		
12	24	6
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42	18	38

KNN algorithm

■ *Application in this project*

For KNN regression, whose labels are X-Y coordinates. The output is derived by averaging K coordinates.

eg:
If detected geomagnetic field value is 25.
K = 2, location (2.5, 2.5);
K = 3, location (2.33, 2);

Reference point location		
(1,3)	(2,3)	(3,3)
(1,2)	(2,2)	(3,2)
(1,1)	(2,1)	(3,1)

Reference point Geomagnetic strength		
12	24	6
48	33	26
42	18	38

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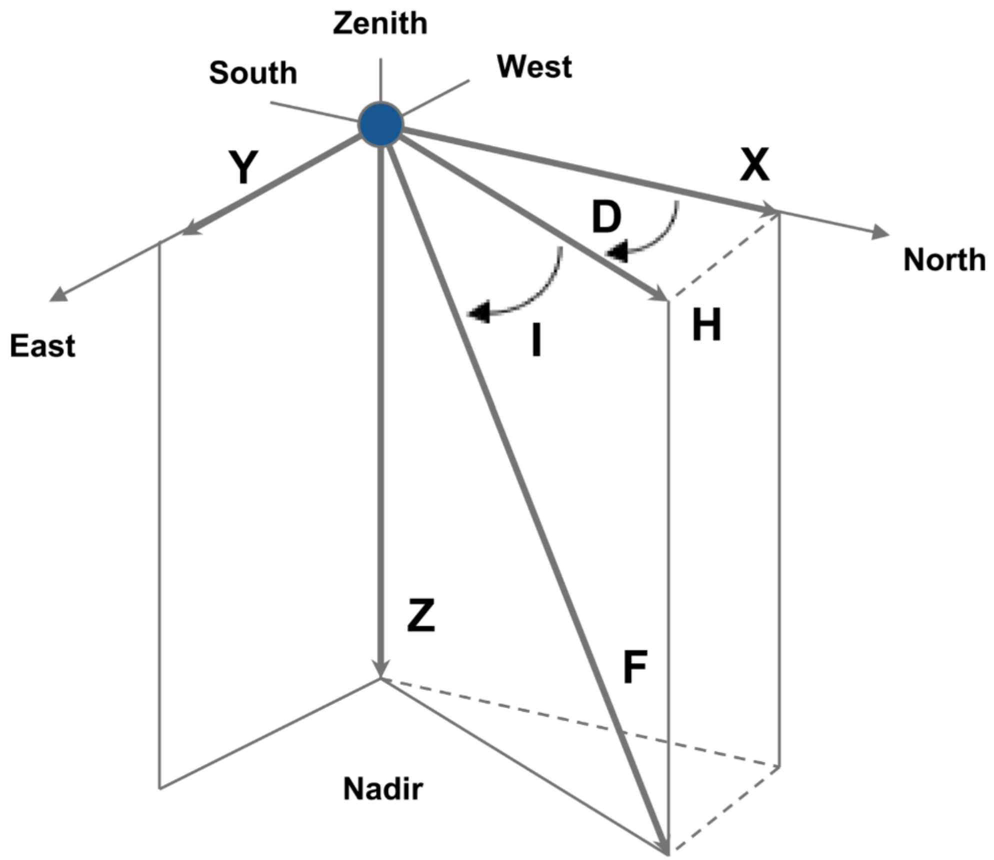
System Design

- Geomagnetic Field Map Generation
- RNN model
- Data Generation for Training

By Zhenghang Zhong (Klaus)

System Design

◆ Geomagnetic Field Map Generation



X: the northly intensity
Y: the easterly intensity
Z: the vertical intensity

H: the horizontal intensity
F: the total intensity
I: the inclination angle
D: declination angle

Figure: The seven elements of geomagnetic field vector B_m associated with an arbitrary point in space.

System Design

◆ Geomagnetic Field Map Generation

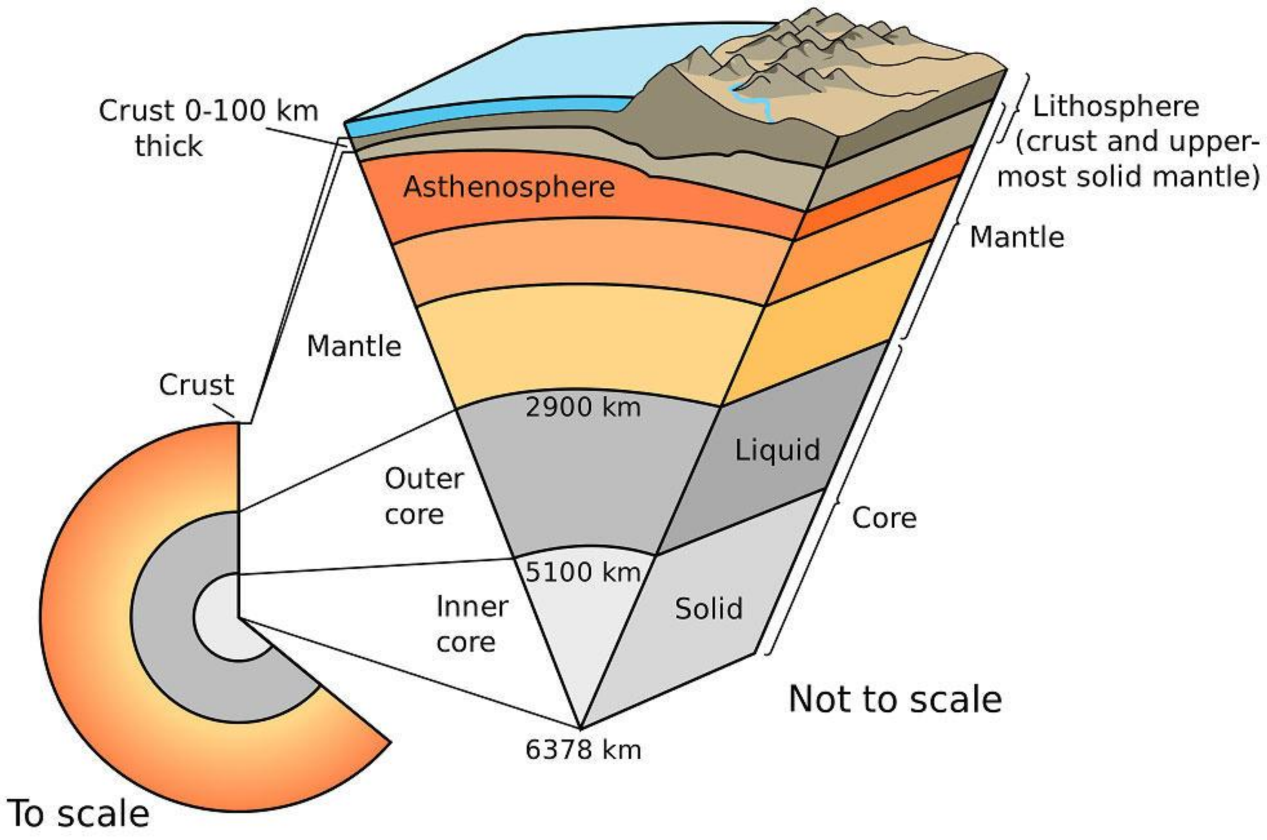
Geomagnetic field Distribution (indoor & outdoor)

Outdoor --- locally similar, worldwide different

- *Liquid-iron outer core --- strongest*
- *Magnetic minerals in the crust and upper mantle --- locally significant*
- *Electric sea water (current) flow*

Indoor --- complex and wider difference

- *Various structures*
  (steel structures, steel shelter doors, elevators, and generators)



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System Design

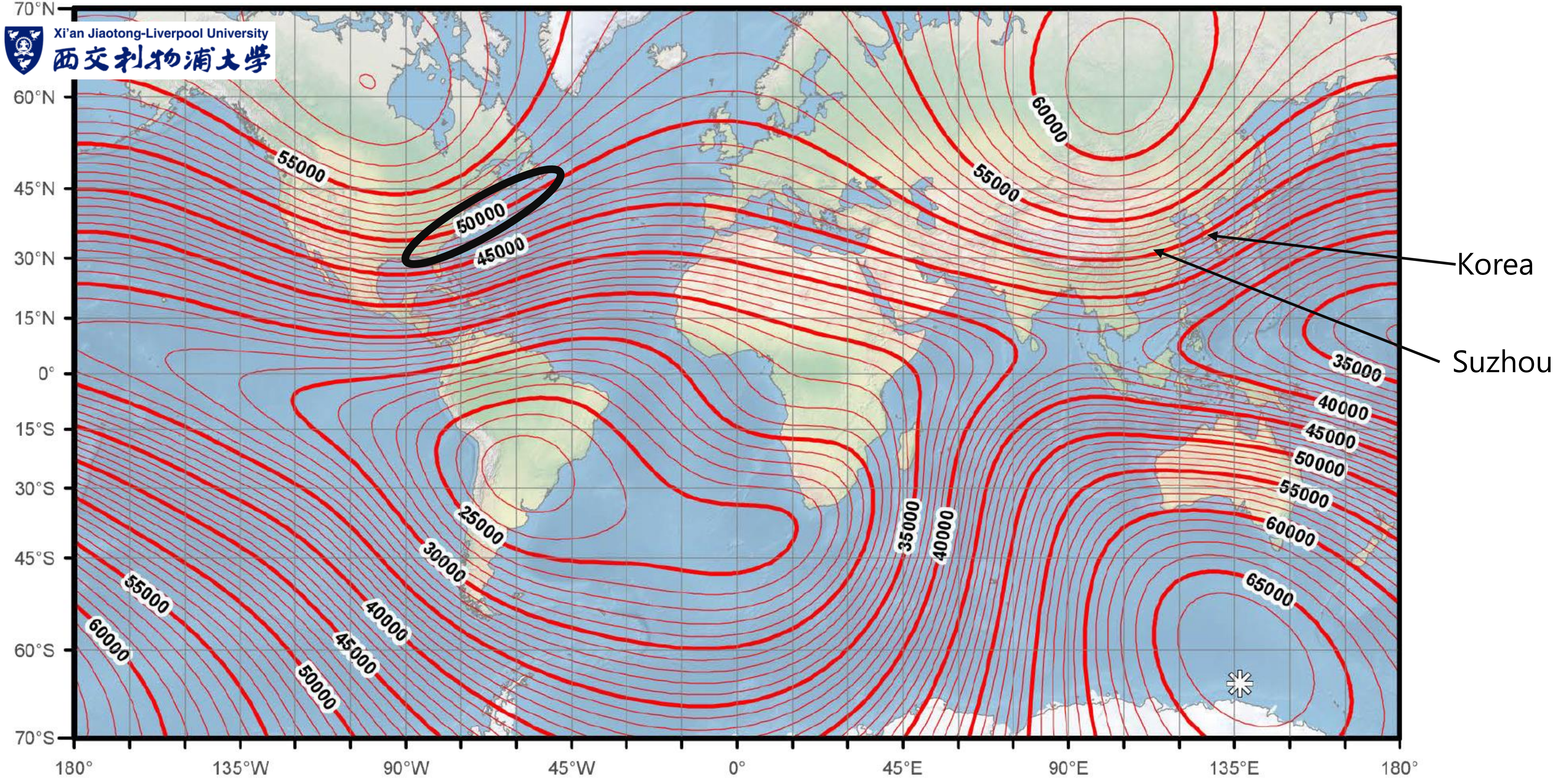
◆ Geomagnetic Field Map Generation

World Magnetic Model (WMM)

- *Core field changes perceptibly from year to year --- secular variation*
- *Unpredictable and non-linear changes in core field*
- *WMM coefficients update every five years, WMM2015 is valid from 2015.0 to 2020.0*

The Republic of Korea is positioned in the 50μT zone

What about in Suzhou, China?



Main field total intensity (F). Contour interval is 1000 nT. Mercator projection.

System Design

◆ Geomagnetic Field Map Generation

Measurement

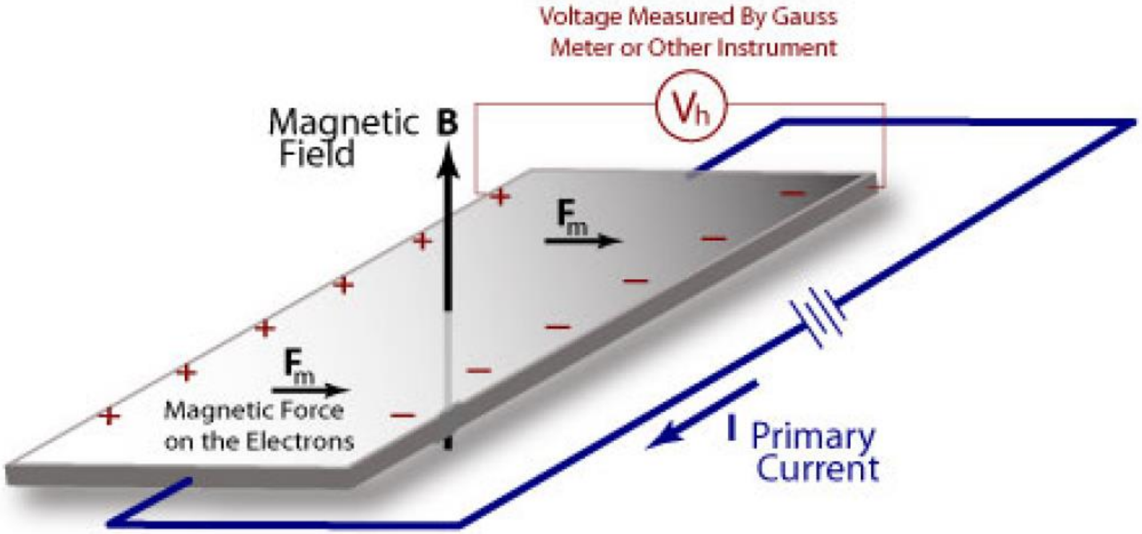


Figure: Geomagnetic Hall Effect

Hardware

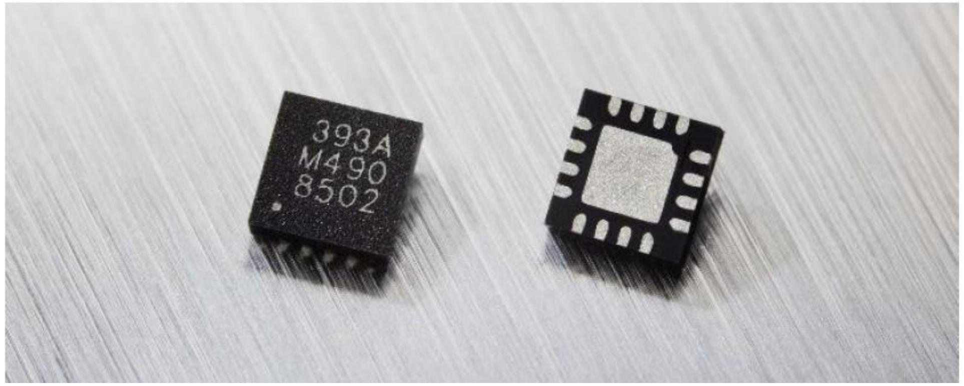
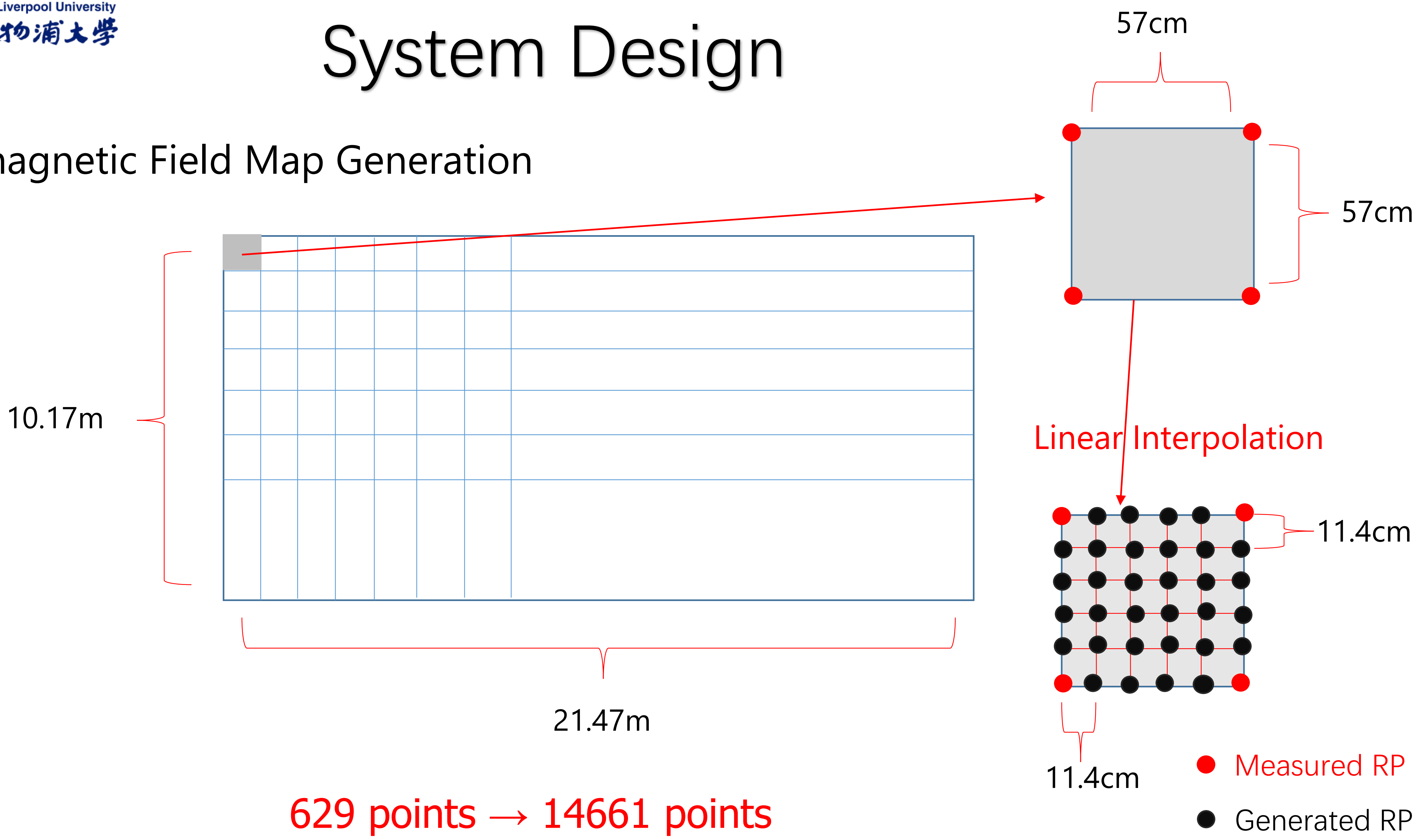


Figure: magnetic field sensor in smart phone

System Design

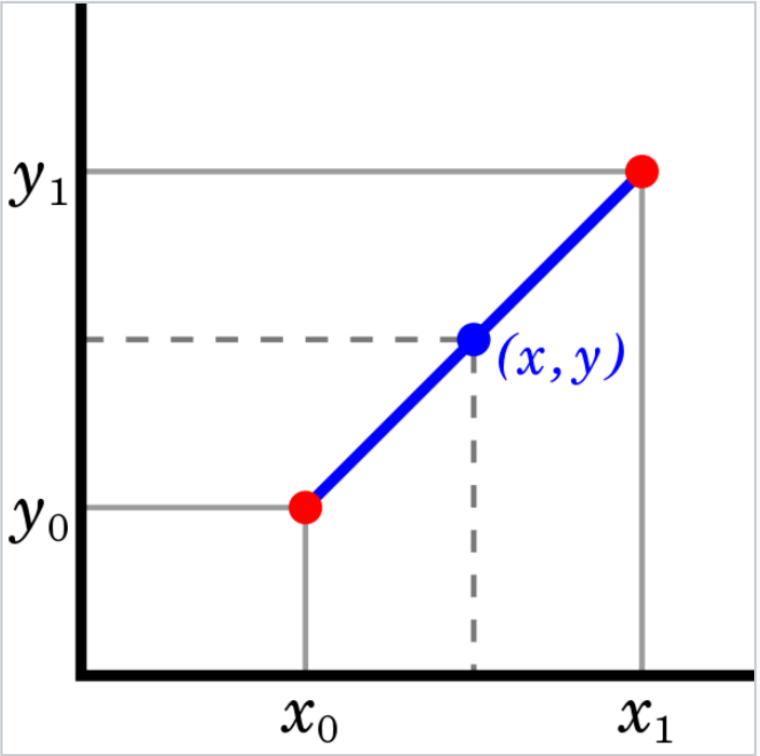
◆ Geomagnetic Field Map Generation



629 points → 14661 points

System Design

◆ Linear Interpolation --- improve resolution



Given the two red points, the blue line is the linear interpolant between the points, and the value y at x may be found by linear interpolation.

Figure: (WiKi) Linear interpolation

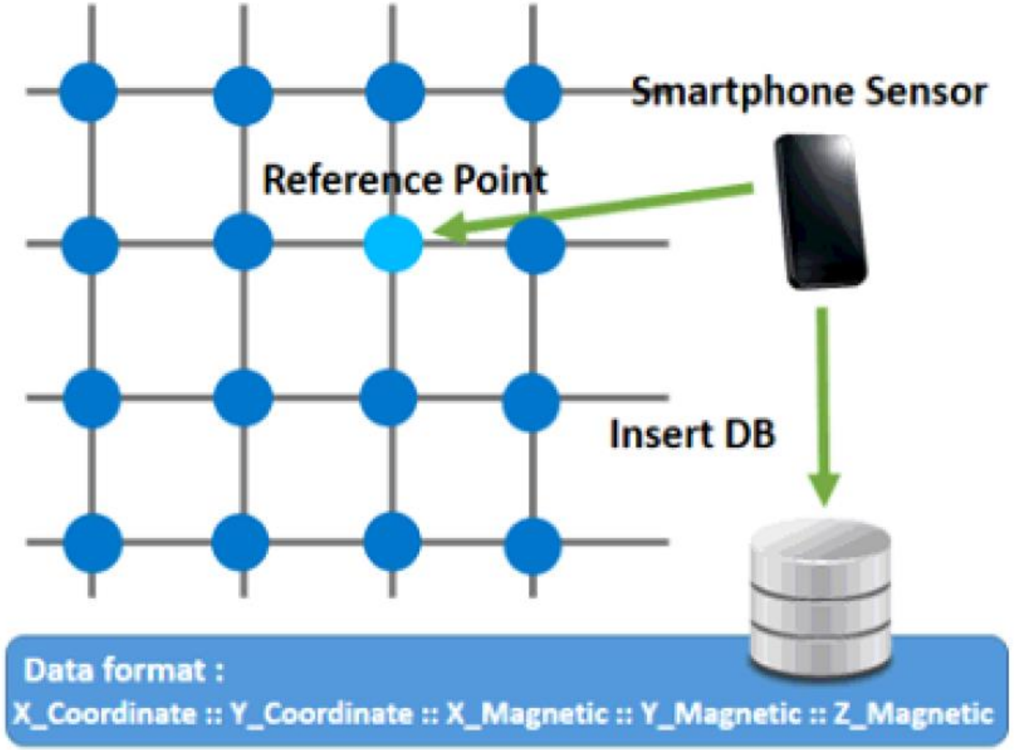
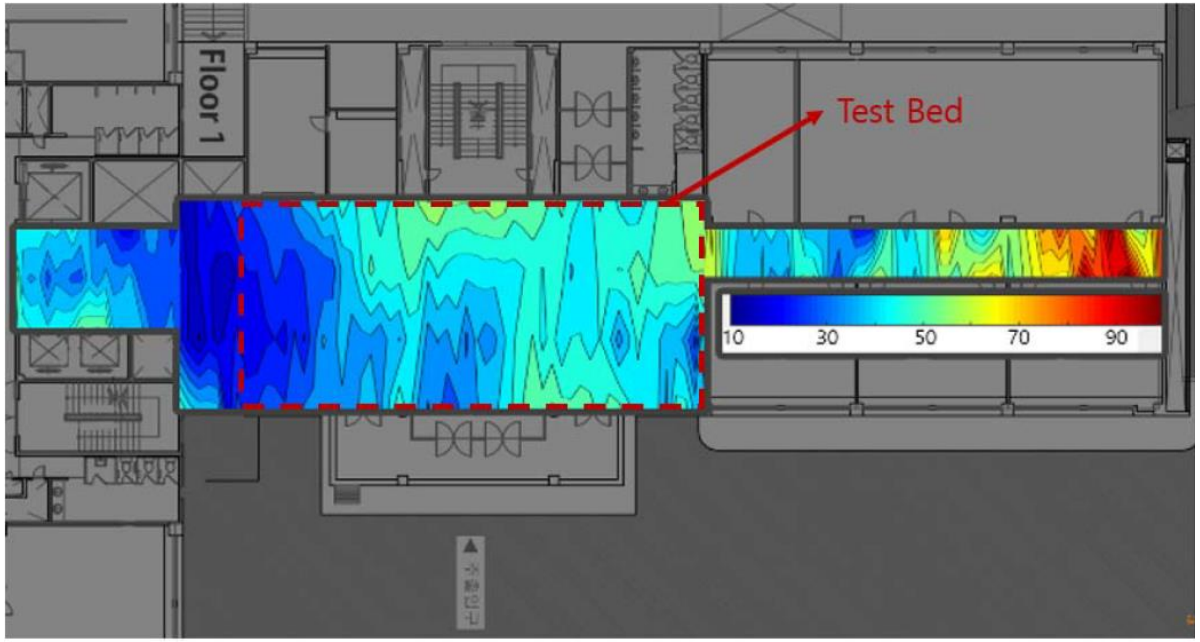


Fig. 6. Geomagnetic field creation process

Figure: Data storage

System Design

◆ Geomagnetic Field Map Generation



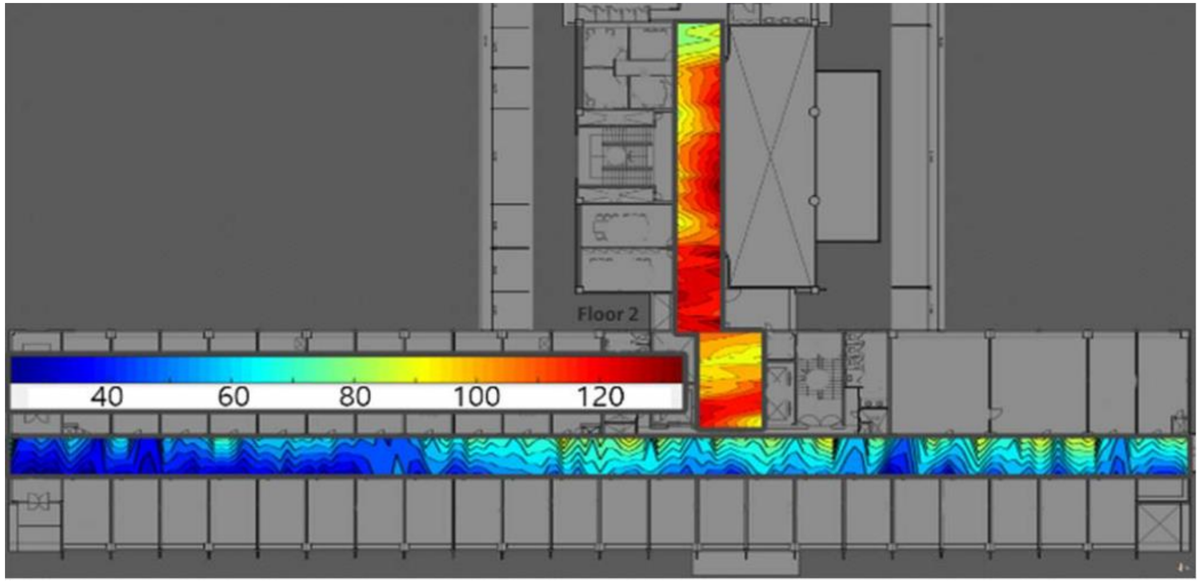


Figure: Geomagnetic field maps of the first and the second floor in EE building of Korea University

System Design

◆ RNN model

- X^t
- Z^t
- W_{in}
- W
- W_{out}

Weights applied to the links from input nodes to hidden nodes, hidden nodes to hidden nodes, and hidden nodes to output nodes.

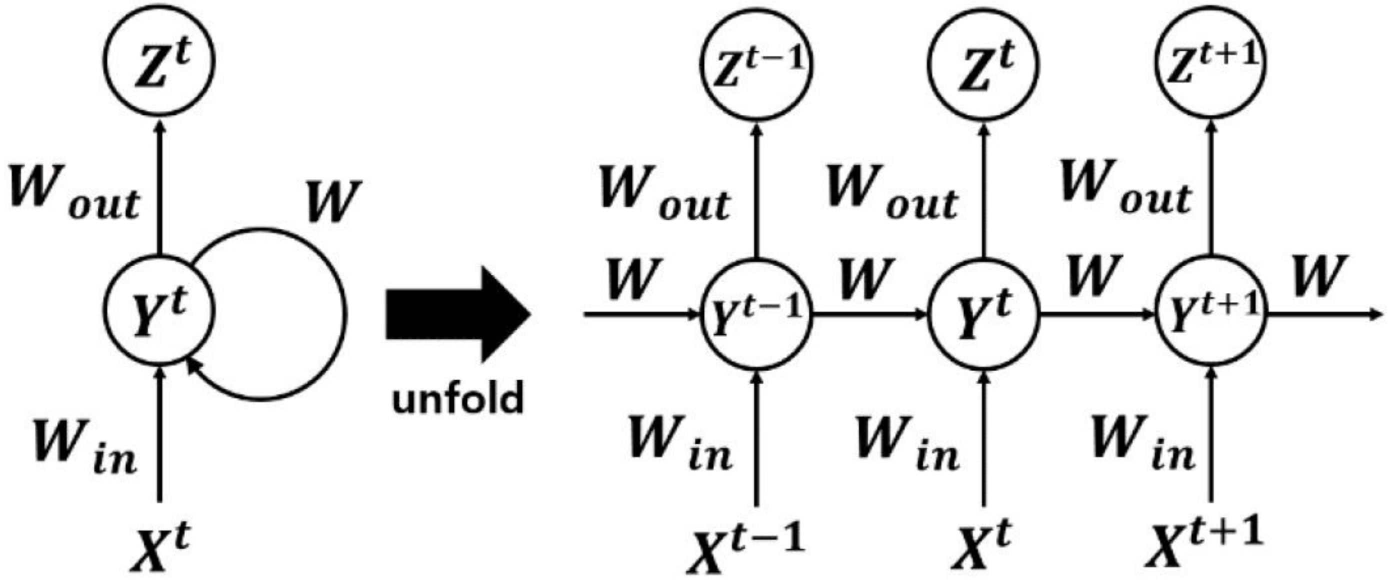


Fig. 7. The structure of a basic Recurrent Neural Network

◆ Output

$$\mathbf{Z_j}^{\mathbf{t}} = \mathbf{f_{out}}(\mathbf{W_{out}}(\mathbf{f}(\mathbf{W_{in}X_i}^{\mathbf{t}} + \mathbf{WY}^{\mathbf{t-1}})) \ (\mathbf{i} \in \{1, 2, 3\}, \mathbf{j} \in \{1, 2\})$$

System Design

◆ Data Generation for Training

➢ Method

- *Geomagnetic field map*
- *Model of pedestrian movements confined in one map*
- *Supervised training*

Using a modified version of random waypoint model

➢ Data

- *Total distance of movements: 750 KM*
- *Total steps: 1,000,000 steps*
- *Data size: 67.9 MB*
- *Training data: 20-step movement as a single trace (50,000 traces)*
- *95% for training, 5% for evaluation*

What is random waypoint model?

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System Design

- Two important factors decide performance: algorithm & training data

  - Random waypoint model

    In mobility management, the **random waypoint model** is a random model for the movement of mobile users, and how their location, velocity and acceleration change over time.

    Firstly used to evaluate mobile ad hoc network routing protocols.

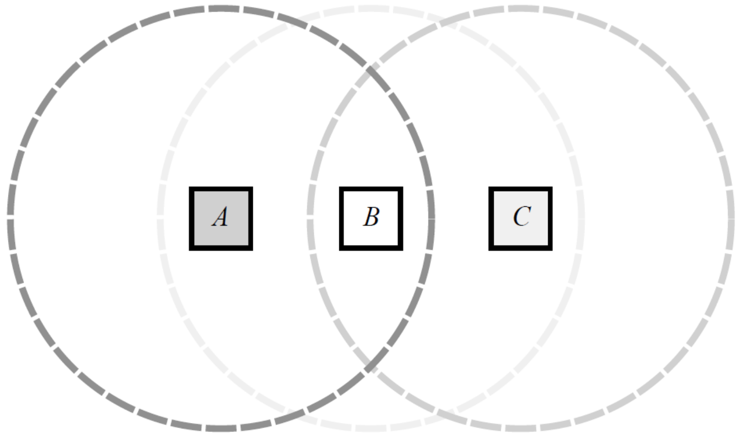

Figure 1 A simple ad hoc network of three wireless mobile hosts

A temporary network without the aid of any established **infrastructure** or centralized **administration**, just use **mobile hosts**.

System Design

- Data sample

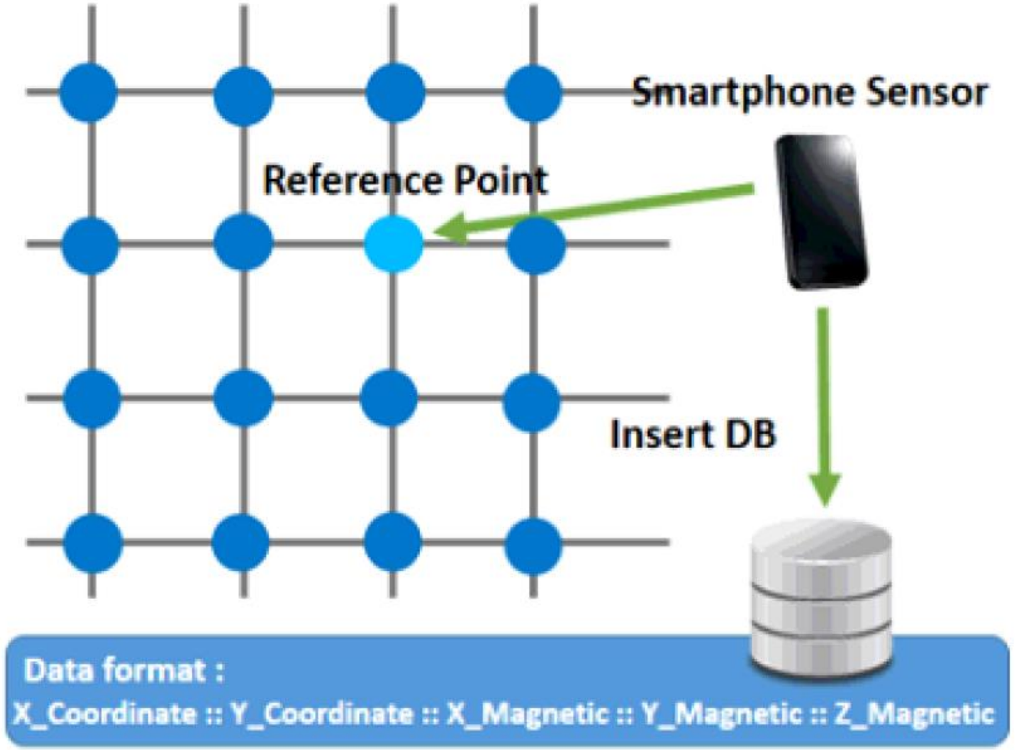

Fig. 6. Geomagnetic field creation process

```
x: 49.981627, y: 74.809191 / x: -12.840187, y: -25.661308, z: -37.471752
x: 50.963254, y: 74.618382 / x: -12.794736, y: -25.671062, z: -36.950087
x: 51.944882, y: 74.427573 / x: -12.737921, y: -25.678593, z: -36.445588
x: 52.926509, y: 74.236764 / x: -12.670318, y: -25.686124, z: -35.968060
x: 53.908136, y: 74.045955 / x: -12.591925, y: -25.693655, z: -35.517505
x: 54.889763, y: 73.855146 / x: -12.502744, y: -25.701187, z: -35.093921
x: 55.871390, y: 73.664337 / x: -12.657172, y: -25.664741, z: -34.612866
x: 56.853017, y: 73.473528 / x: -12.824508, y: -25.612549, z: -34.131976
x: 57.834645, y: 73.282719 / x: -12.972065, y: -25.549569, z: -33.660976
x: 58.816272, y: 73.091910 / x: -13.099843, y: -25.475800, z: -33.199866
x: 59.797899, y: 72.901101 / x: -13.207841, y: -25.391242, z: -32.748646
x: 60.779526, y: 72.710292 / x: -13.118590, y: -25.061164, z: -32.538463
x: 61.761153, y: 72.519483 / x: -12.991776, y: -24.680408, z: -32.394065
x: 62.742781, y: 72.328674 / x: -12.876650, y: -24.312239, z: -32.255061
x: 63.724408, y: 72.137865 / x: -12.773212, y: -23.956657, z: -32.121451
x: 64.706035, y: 71.947056 / x: -12.681461, y: -23.613662, z: -31.993236
```

Fig. 8. Experimental data sample

1 unit = 11.4 cm

μT

Conclusion

- Experimentation Environment
- Neural Network Training
- Experiment results

Conclusion

◆ Experimentation Environment

Category	Machine / Tools
CPU	Intel i7-6900K 3.2GHz (8C16T)
GPU	NVIDIA Geforce GTX1080 8GB
RAM	DDR3 32GB 2133MHz
OS	Ubuntu Server 16.04 LTS
Language	Python 3.5
Library	Google Tensorflow 1.2 NVIDIA cuDNN v5.1

Conclusion

◆ Neural Network Training

Parameters

- *Hidden nodes*
- *Mini-batch size*
- *Execution epochs (iteration over entire dataset)*
- *Learning rate*

Methods

- *Standard normal distribution (biases and weights)*
- *Optimizer: Adam*
- *Loss function: MSE(mean square error)*
- *Repeated feed-forward propagation of inputs, back propagation of errors*

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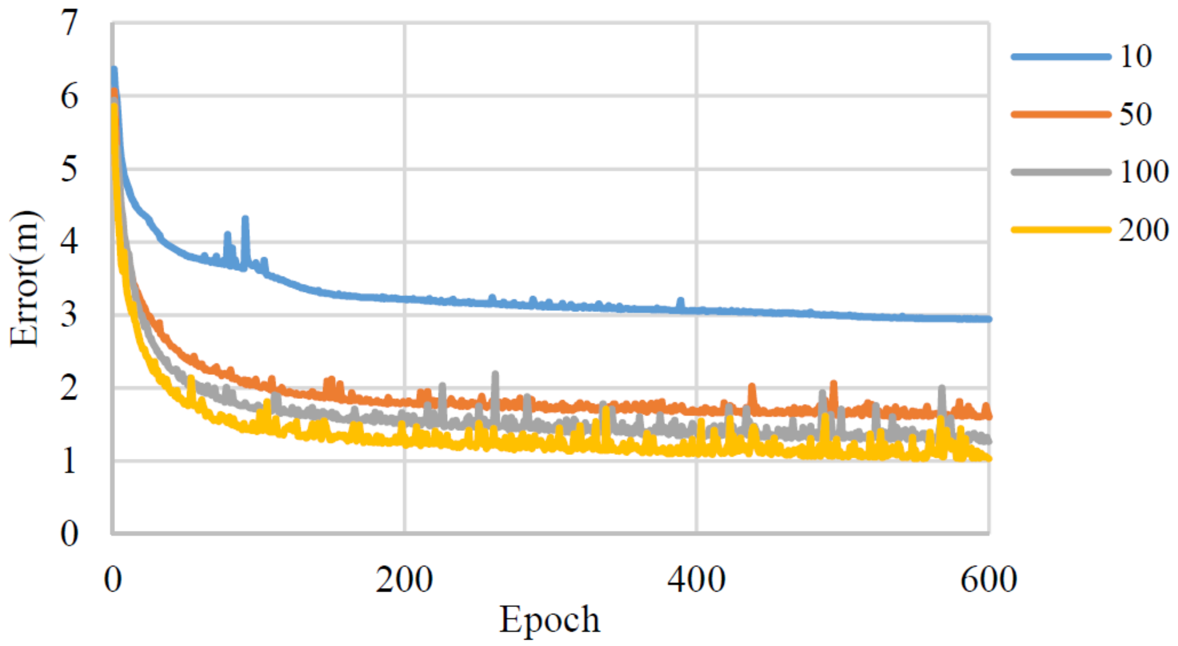
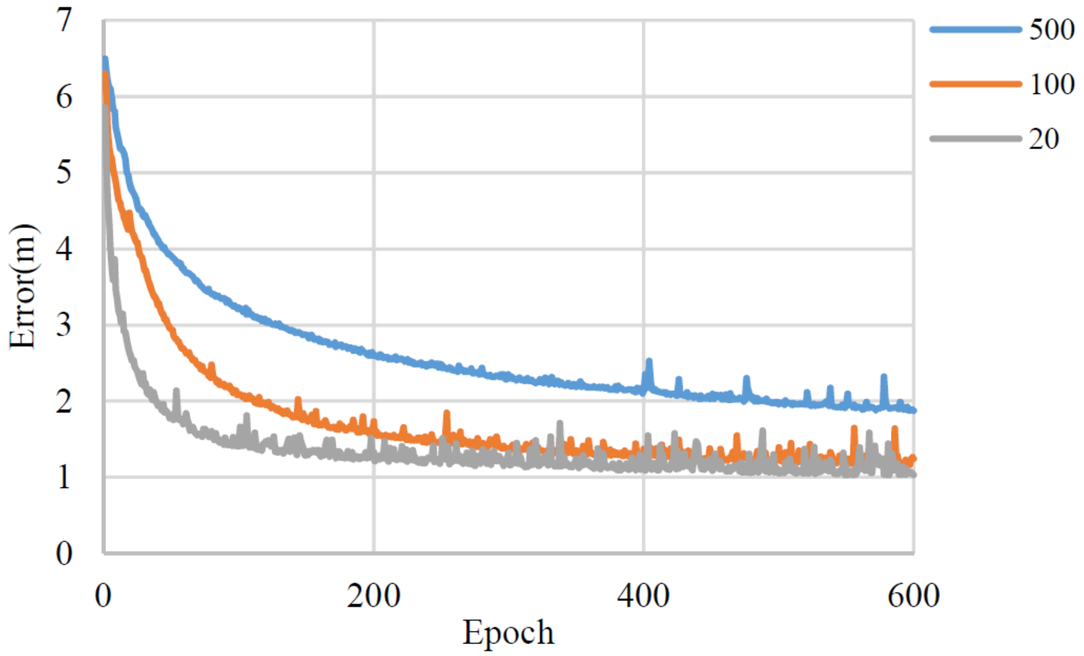
Conclusion

◆ Neural Network Training

☐ The number of hidden nodes



☐ The mini-batch size



Conclusion

◆ Neural Network Training

Overall parameters

Category	**Value**
Neural model	Recurrent Neural Network
Loss function	Mean Squared Error (MSE)
Optimizer	Adam
Hidden node	200
Learning Rate	0.001
Mini-batch size	20

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Conclusion

◆ Experiment results

Test:

- *5% evaluation data (50,000 steps = 2500 traces) of modeled traces*
- *RNN model*

Results:

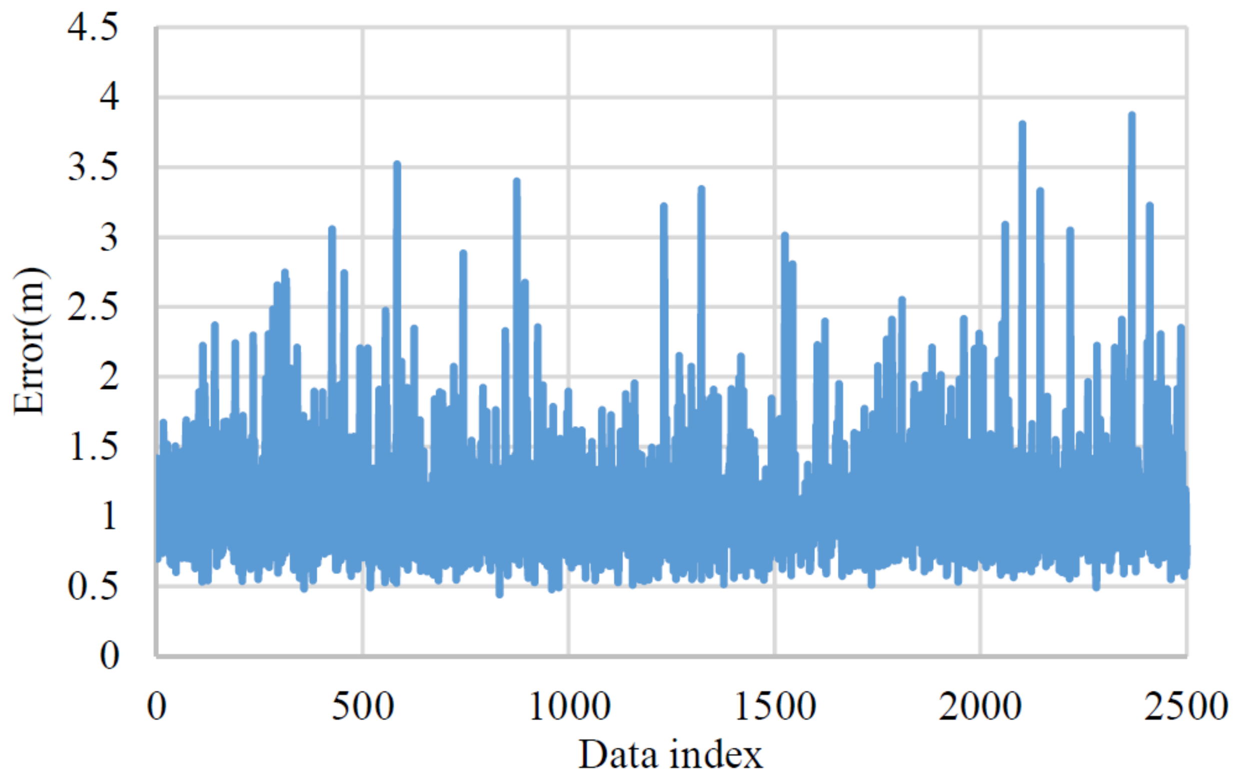

Figure: distribution of localization error

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Conclusion

◆ Experiment results

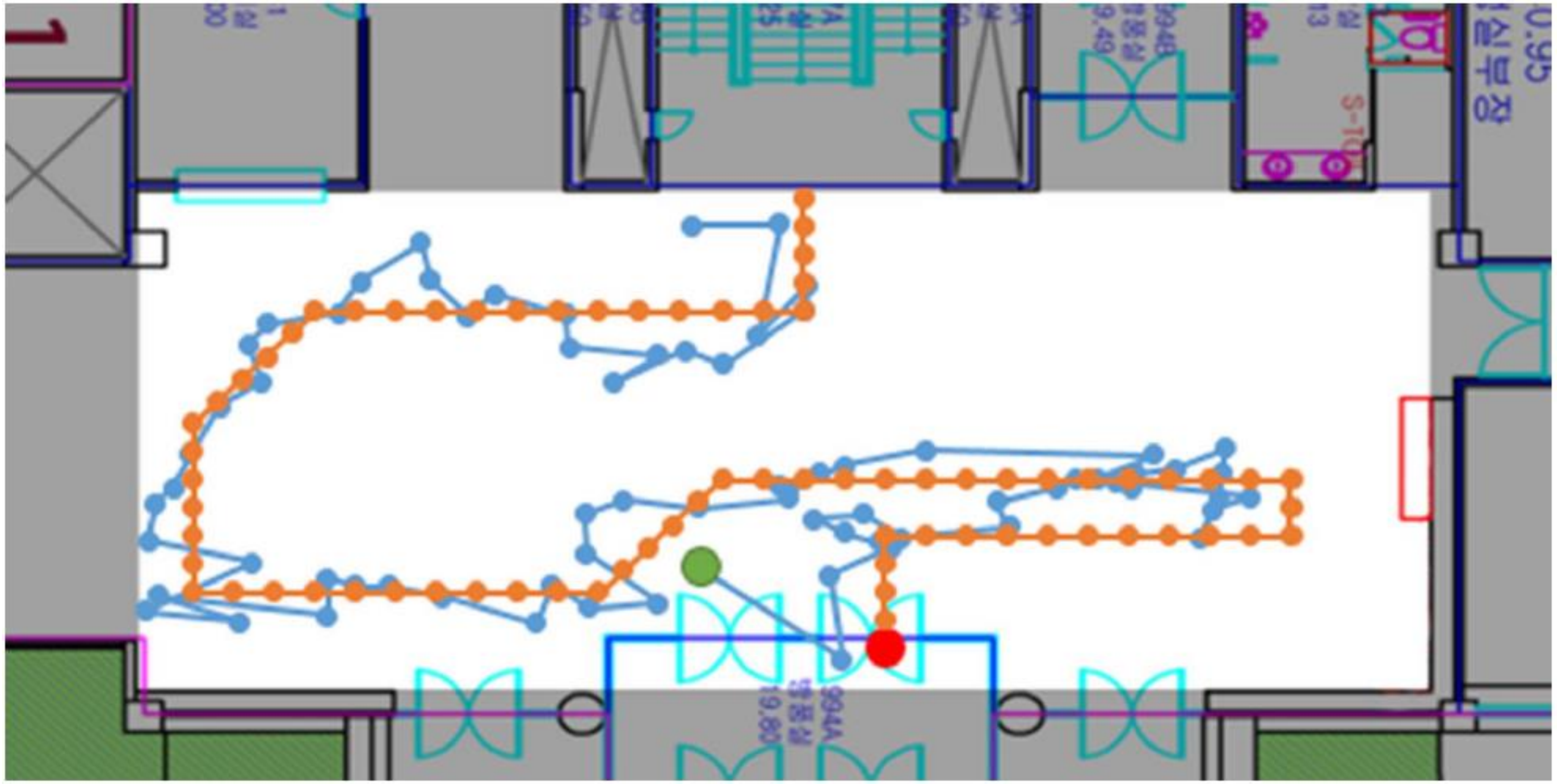
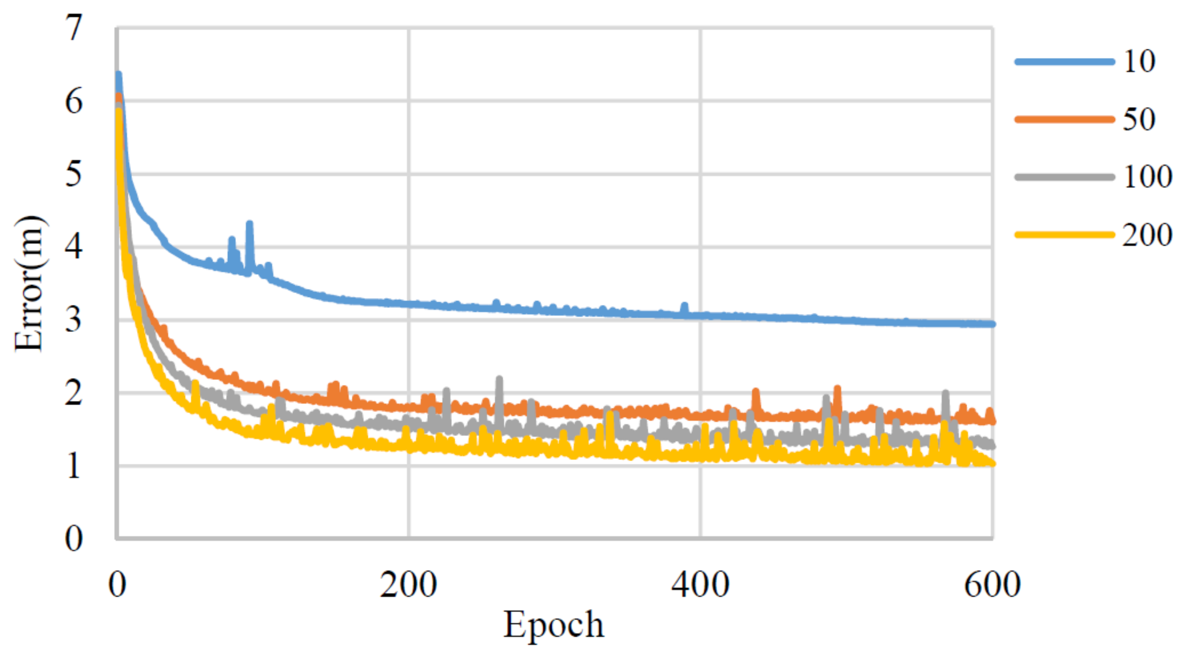


Figure: Evaluation results for a sample path

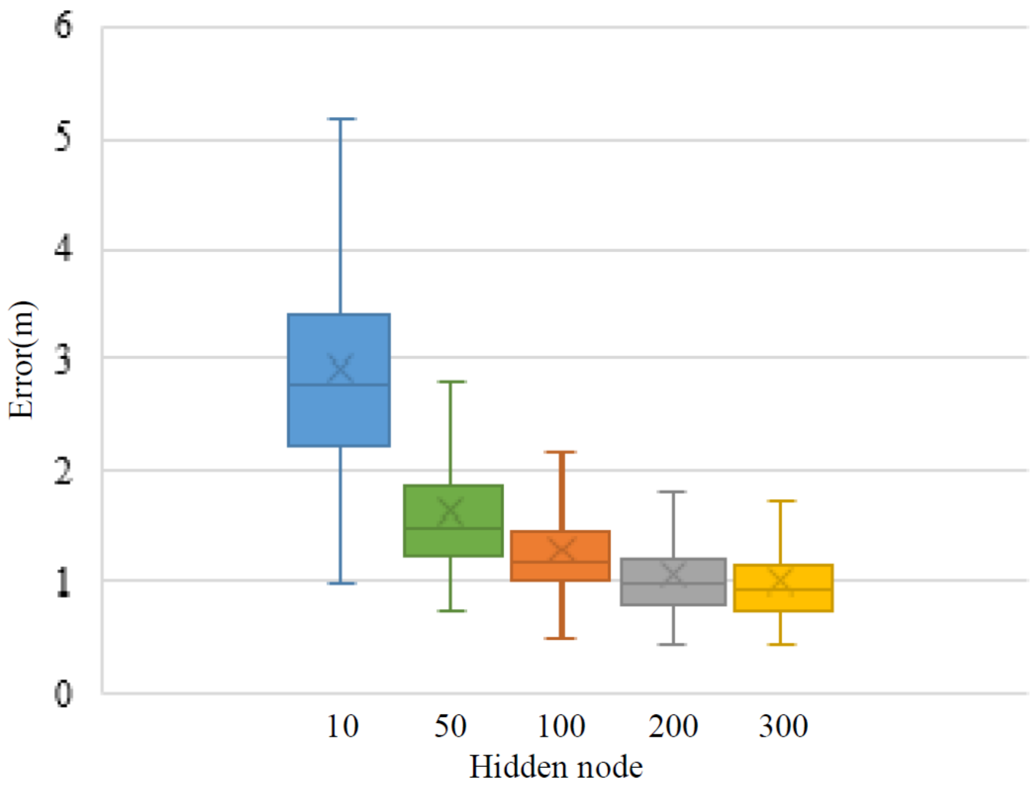
Conclusion

◆ Experiment results

The number of hidden nodes



Localization performance in terms of the number of hidden nodes



300 hidden nodes: Overfitting

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Evaluation

◆ Achievements

- *Error range: 0.441m – 3.874m*
- *Average error: 1.062m*
- *Smooth and continuous movement tracking*

◆ Drawbacks

- *WMM coefficients update every five years*
- *Strong environment dependence*

◆ Advantage

- *Rather stable geomagnetic value*
- *Very low cost*
- *Less collection work*

◆ Improvements

- *Advanced RNN model (LSTM, bidirectional RNN)*
- *Mapping*
  (e.g. multi-floor, multi-building)
- *Data collection and traces generation (improved random waypoint model)*
  (e.g. random walk model, random direction model)

Questions?

END