Machine learning and indoor mapping in support of a Fit For Purpose 3D Cadastre

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Main Objective

*Development of a **fit-for-purpose** technical framework for the implementation of 3D **crowdsourced** cadastral surveys everywhere, including even regions that still lack a 2D cadastral data registration*

Absence of accurate registration basemap

- ✓ *Informal constructions*
- ✓ *Self-made cities*
- ✓ *Old-constructions*
- ✓ *etc.*

Indoor Positioning System (IPS)

3D Indoor Cadastre

❖ **Current research trends:**

- ✓ *Low-cost equipment*
- ✓ *Crowdsourcing techniques*
- ✓ *Machine learning techniques*
- ✓ *Automated procedures*
- ✓ *Mobile services (m-services) & web services*
- ✓ *Open-source software (OSS)*
- ✓ *Standardized international data models, such as Land Administration Domain Model (LADM)*

Minimize cost, time and prerequisites of the required surveys

3D Cadastre - *Current Research*

- ✓ **LADM-based 3D Cadastres (LADM ISO 19152)**
  Flexible conceptual schema for 2D/3D Cadastres – based on a Model Driven Architecture (MDA)
- ✓ **Linking LADM with physical models**
  Application schemas & Technical models (CityGML, IndoorGML, BIM/IFC, LandXML etc.)
- ✓ ***2D/3D Crowdsourcing cadastral surveys***
  *Minimize **cost** and **time** of the required surveys*

➢ ***3D Indoor Cadastral Recording***

- ✓ *2D architectural plans* — ***Limited availability***

- ✓ *GPS sensor - smartphone's GPS*
- ✓ *GNSS receiver device - Trimble R2GPS GNSS / EOS Arrow Gold RTK GNSS*

Weak Indoor Positioning Accuracy

→ ***Best fitted Solution***
Indoor positioning System (IPS)

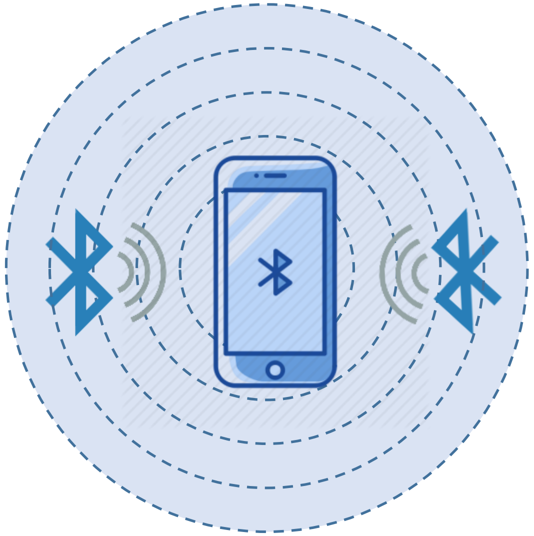
Indoor Position Systems (IPS) - *Current Research*

- ✓ Technologies – Bluetooth, ZigBee, Wi-Fi
- ✓ Techniques – Fingerprinting, Lateration, Dead Reckoning
- ✓ Measurements – Received Signal Strength Indicator (RSSI)

Modelling Position Data

- ✓ *Machine Learning Methods*
  k-Nearest Neighbors (KNN), Neural Networks and Support Vector Machines (SVM) etc.

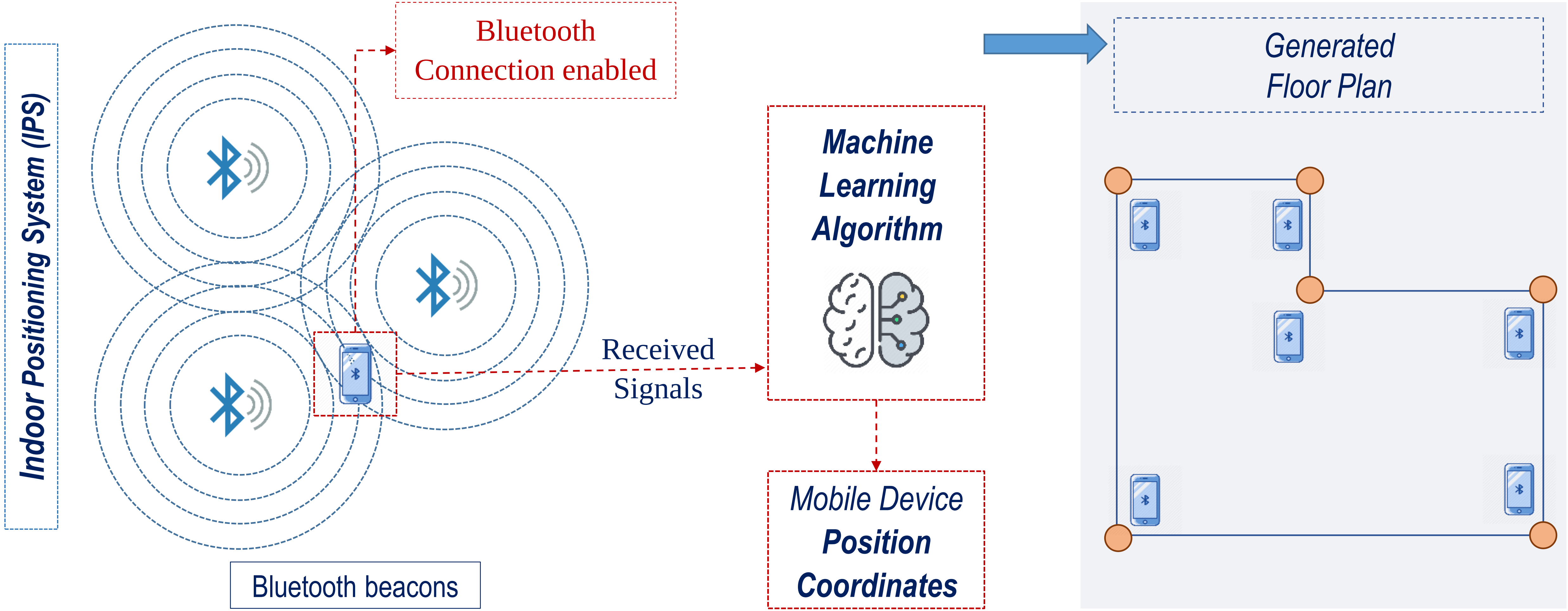
Accuracy improvement



- ✓ *Relatively high accuracy*
- ✓ *Low cost*
- ✓ *Low Hardware Requirements*
- ✓ *Easy integration*
- ✓ *Low power consumption*

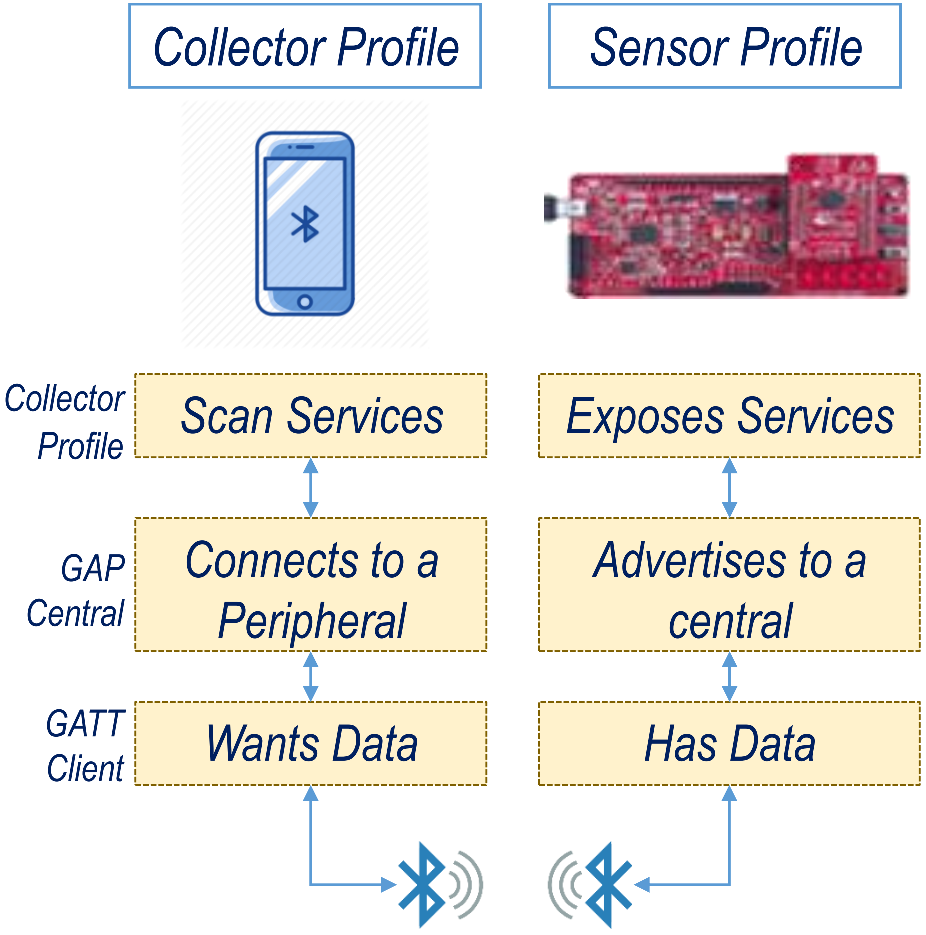
Low-cost Location-based Applications

Proposed 3D Indoor Crowdsourced Cadastral Mapping – System Architecture



The Sensing Infrastructure

- Technology
  - ✓ *Bluetooth Beacons*
    UHF 2.402 to 2.480 GHz
- Spatial correlation
  - ✓ *Beacons assignment with physical coordinates*
  - ✓ *Received Signal Strength Indicator (RSSI)*
- Main modality
  - ✓ *multiple Bluetooth signals*
    position error minimization ~ cm accuracy



The Deep Learning Framework for Coordinate Estimation

- ***N** available Bluetooth sensors*
- *Distortion of signals:* $\boldsymbol{X_i}(t),\ i = 1,2, \dots N$
- *Space position estimates:* $y_c = f(X(t_i))$ **(1)**
- ***Long Short Term Memory (LSTM) Network***

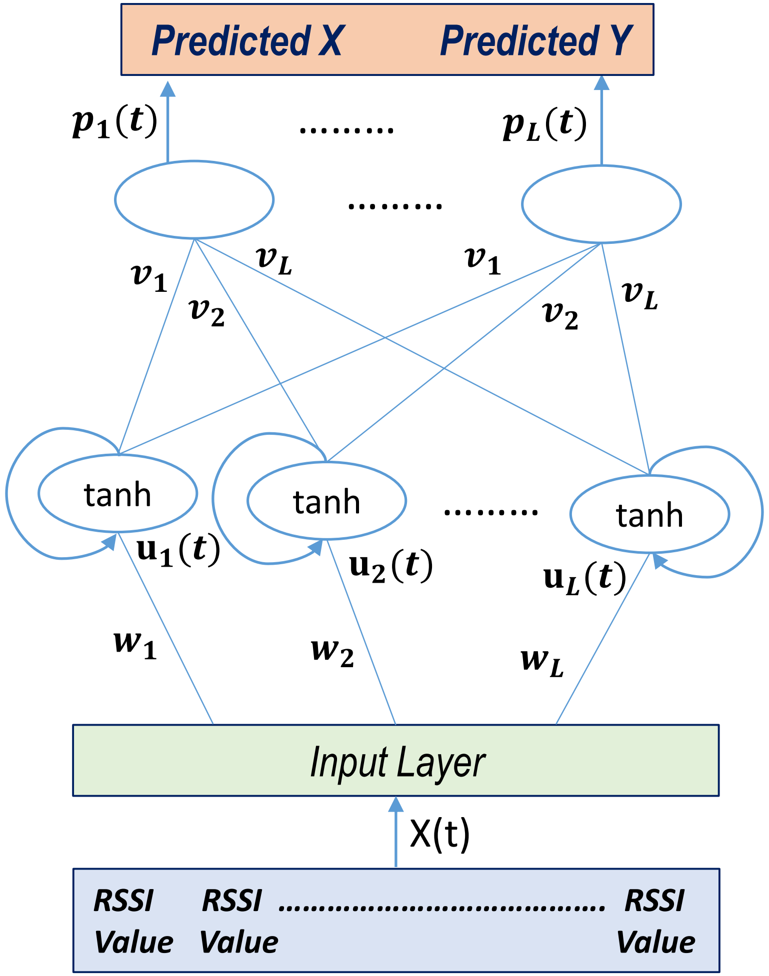
L: *hidden Neurons*

$$s_c(p_i) = \mathbf{u}_j(t)^T \cdot \mathbf{v}_j,\ j = 1,2,\dots K \quad \textbf{(2)}$$

$$\mathbf{u}_j(t) = \begin{bmatrix} u_{j,1}(t) \\ \vdots \\ u_{j,L}(t) \end{bmatrix} = \begin{bmatrix} sigmoid(\mathbf{w}_{j,1}^T \cdot \boldsymbol{x}(t)) \\ \vdots \\ sigmoid(\mathbf{w}_{j,L}^T \cdot \boldsymbol{x}(t)) \end{bmatrix} \quad \textbf{(3)}$$

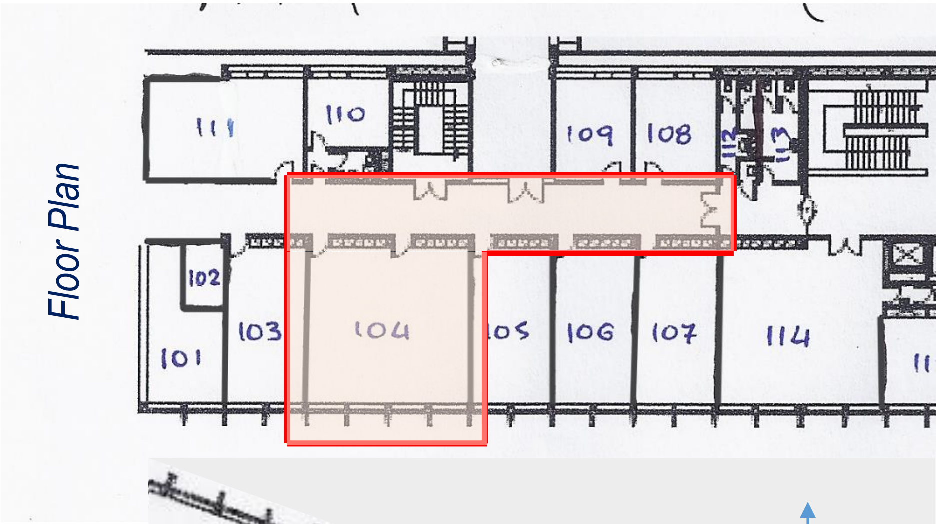
$$\boldsymbol{u_i}(nt) = sigmoid(\mathbf{w}_i^{\mathrm{T}} \cdot \boldsymbol{x}(t) + \vec{\mathbf{r}}_i^{\mathrm{T}} \cdot \mathbf{u}(t-1) + \overleftarrow{\mathbf{r}}_i^{\mathrm{T}} \cdot \mathbf{u}(t+1)) \quad \textbf{(4)}$$

- *Bayesian Optimization - best parameters selection & error E minimization*



Practical Experiment (1/3)

- **Test Area**
  - ✓ 1st Floor of SRSG, NTUA
  - ✓ total area: ~100m^2
- **Technical equipment**
  - ✓ **4** Raspberry Pi Bluetooth devices
  - ✓ A smartphone, with Bluetooth capabilities



- **Dataset**
  - ✓ geodetic coordinates (X,Y) of **49** points in Greek Grid
  - ✓ **4** deployment stations for the Raspberry Pi
  - ✓ **45** points: a) the RSSI measurements,
    b) the device ID and,
    c) the signal transmitting time

1 min per point → 100 measurements / point

Practical Experiment (2/3)

- **Software & Hardware tools**
  - ✓ Python 3.6
  - ✓ Keras 2.4.3
  - ✓ Tensorflow 2.3.0
  - ✓ Intel® Core™ i5 -7200U CPU (2.50 GHz) with Radeon ™ R5 M430
- **LSTM Classifier**
  - ✓ input and output layers
  - ✓ 2 LSTM Layers
  - ✓ Sigmoid activation function
- **Training & Testing Scenarios**
  - ✓ 1st Scenario: RAS1, RAS2, RAS3 and RAS4
  - ✓ 2nd Scenario: RAS1, RAS2 and RAS3
- **Dataset:** ✓ 80% - Training ✓ 20% - Testing

Scenario 2

Practical Experiment (3/3)

- ***Training***
  - ✓ *Duration ~ 4hr*
- ***Testing***
  - ✓ *Position Estimation < 1 sec*
  - ✓ *Average estimation accuracy ~15.2cm*
- ***Metrics***

	Accuracy	Precision	Recall	F1-score
Scenario 1	83.47 %	87.63%	82.88%	85.19%
Scenario 2	68.72%	72.14%	68.23%	70.13%

Scenario 2

Conclusions

Innovative approach* - *3D Indoor Cadastral Surveys

- ✓ *3D **Crowdsourcing** Techniques* - Citizens' participation – ***errors minimization***
- ✓ ***Cost effective** and **time consuming** solution / automation*
  usage of modern *low-cost IT tools, m-services*
- ✓ ***Machine Learning Techniques***
  LSTM network with optimised hyperparameters - accurate ***Indoor Localisation***
- ✓ ***Bluetooth** technology*
  relatively **low-cost & portable** with small dimensions ~ cm

Overcoming difficulties:

- ✓ *Plan / Map availability*
- ✓ *GPS / GNSS*
  Indoor weaknesses

Fit for Purpose 3D Cadastre

Future Work

- ✓ *Integration between the developed* ***indoor positioning system*** *and a* ***cadastral mobile application*** *able to automatically provide the 3D model of the property unit*

- ✓ *Adoption of* ***more complex deep machine learning architectures*** *multi-channel recurrent neural networks*
  - *processing simultaneously signals from heterogeneous sensors (e.g., Bluetooth and WiFi signals, Channel State Information of WiFi signals)*

- ✓ ***Accuracy incensement***
  - *reduce granularity of the targets positions labels*
  - *Model training from multiple buildings*

- ✓ *Development of a fitted framework for furnished places*
  limited physical access to the borders of the room

Thank you for your attention!

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