Applying Deep Neural Networks to Improve UAV Navigation in Satellite-less Environments

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1. Motivation

UAV navigation through indoor environments [Warehouses goods movement] $->$ No convergence towards a uniquely accepted solution

(1) Industry giants

- Indoor Location Competition 2.0 (Microsoft Indoor Location Competition)
  - 2D Category
    - WiFi and/or inertial measurement unit based
  - 3D Category
    - UWB, ultrasound, etc.
    - Deployment of up to 10 anchor devices in the evaluation space

(2) Academy interest

- Attracting significant research interest
- Papers appearing in leading journals and magazines

2. Problem Formulation

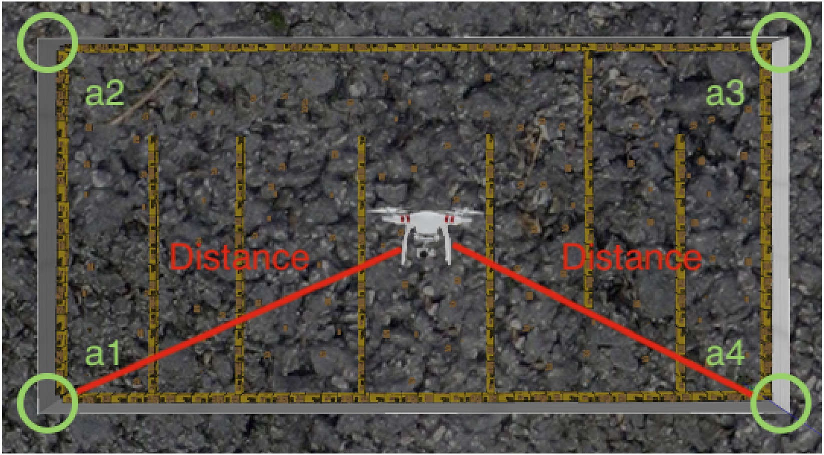


Figure 1: Problem introduction.

2. Problem Formulation

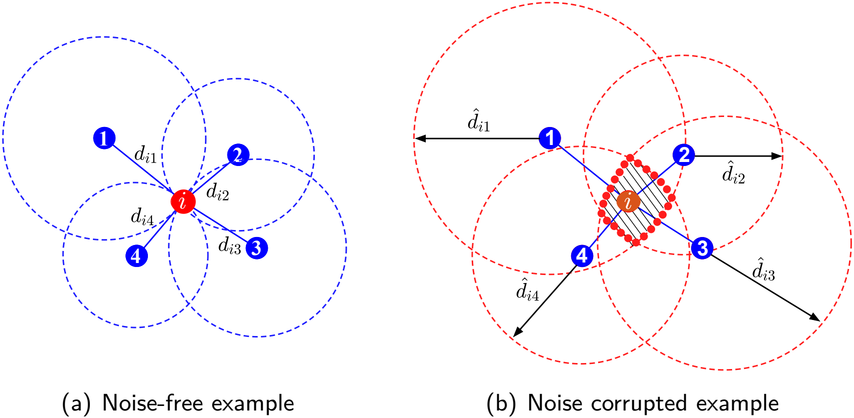


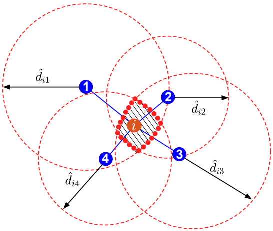
Figure 2: Illustration of range-based localization principle.

2. Problem Formulation

- Measurement model:

$$d_{i,k}^{(t)} = \|\boldsymbol{x}^{(t)} - \boldsymbol{a}_i\| + n_{i,k}^{(t)}, \qquad (1)$$

  - $n_{i,k}^{(t)} \sim \mathcal{N}\left(0, (\sigma_{i,k}^{(t)})^2\right)$



- ML estimator:

$$\widehat{\boldsymbol{x}}^t = \arg\min_{\boldsymbol{x}^t} \sum_{i=1}^{N} \frac{\left(d_i^{(t)} - \|\boldsymbol{x}^{(t)} - \boldsymbol{a}_i\|\right)^2}{2(\sigma_i^t)^2}$$

- The ML problem
  - is non-convex
  - cannot be tackled directly
  - Presents discontinuity in the anchors coordinates

2. Problem Formulation

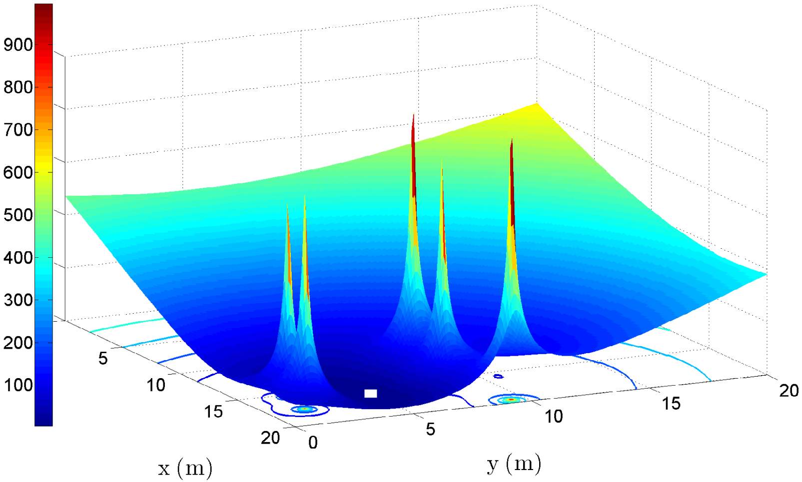


Figure 3: A possible realization of the ML function.

- GTRS MAP Estimator (Estimate the UAV location)

$$\begin{aligned} &\underset{\boldsymbol{z}^{(t)}}{\text{minimize}} \;\; \|\boldsymbol{A}^{(t)}\boldsymbol{z}^{(t)} - \boldsymbol{b}^{(t)}\|^2 \\ &\text{subject to} \\ &\left(\boldsymbol{z}^{(t)}\right)^T \boldsymbol{D}\boldsymbol{z}^{(t)} + 2\boldsymbol{f}^T\boldsymbol{z}^{(t)} = 0, \end{aligned} \tag{2}$$

$$\textit{with } \boldsymbol{z}^{(t)} = \left[\left(\boldsymbol{\theta}^{(t)}\right)^T, \|\boldsymbol{x}^{(t)}\|^2\right]^T \in \mathbb{R}^5, \boldsymbol{D} = \begin{bmatrix} \boldsymbol{I}_2 & \boldsymbol{0}_{2\times 3} \\ \boldsymbol{0}_{3\times 2} & \boldsymbol{0}_{3\times 3} \end{bmatrix} \in \mathbb{R}^{5\times 5},$$

$$\boldsymbol{f} = \begin{bmatrix} \boldsymbol{0}_{4\times 1} \\ -1/2 \end{bmatrix} \in \mathbb{R}^5, \boldsymbol{\theta}^{(t)} = \left[\left(\boldsymbol{x}^{(t)}\right)^T, \left(\boldsymbol{v}^{(t)}\right)^T\right]^T \in \mathbb{R}^4$$

2. Problem Formulation

- Estimate the direction

$$\phi^{(t)} = \arctan\left(\frac{x_{\text{dest,y}} - \hat{x}_{\text{y}}^{(t)}}{x_{\text{dest,x}} - \hat{x}_{\text{x}}^{(t)}}\right), \tag{3}$$

- Subsequent Position

$$\boldsymbol{x}^{(t+1)} = \boldsymbol{S}\left[(\boldsymbol{x}^{(t)})^T, (\boldsymbol{u}^{(t)})^T\right]^T \textit{with}, \tag{4}$$

$$\boldsymbol{u}^{(t)} = \begin{bmatrix} \cos(\phi^{(t)}) \\ \sin(\phi^{(t)}) \end{bmatrix} \in \mathbb{R}^2,$$

$$\boldsymbol{S} = \begin{bmatrix} 1 & 0 & \Delta & 0 \\ 0 & 1 & 0 & \Delta \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2. Problem Formulation

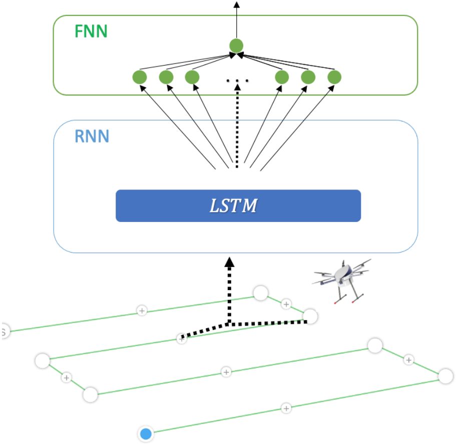


Figure 4: The proposed neural network pipeline for the waypoints prediction.

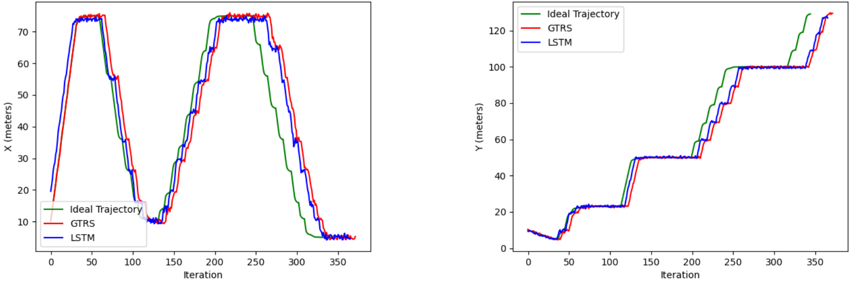


Figure 5: Comparison between the GTRS prediction, the LSTM prediction and the ground truth position of the UAV with $LB = 5$ and a TP of 70%.

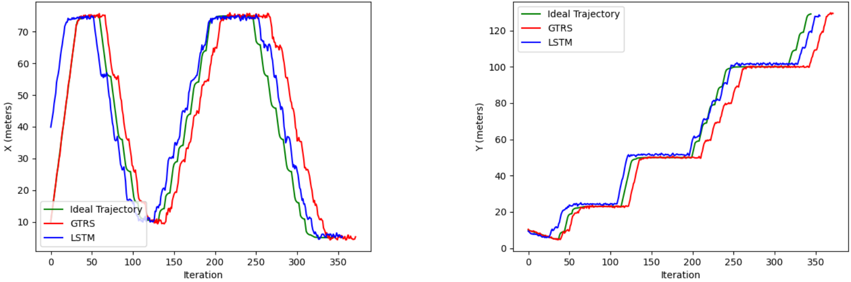


Figure 6: Comparison between the GTRS prediction, the LSTM prediction and the ground truth position of the UAV with $LB = 15$ and a TP of 70%.

3. Numerical Results

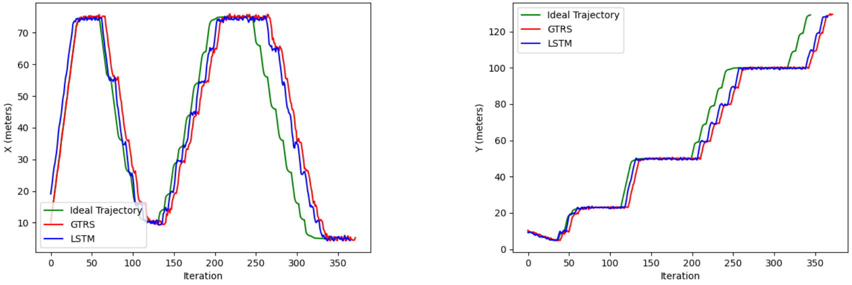


Figure 7: Comparison between the GTRS, the LSTM and the desired trajectory of the UAV with $LB = 5$ and a TP of 100%.

3. Numerical Results

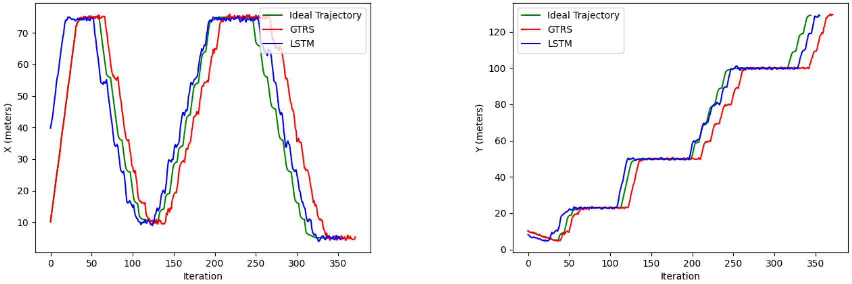


Figure 8: Comparison between the GTRS, the LSTM and the desired trajectory of the UAV with $LB = 15$ and a TP of 100%.

3. Numerical Results

Table 1: Average execution time per trajectory.

Algorithm	Execution time
GTRS	0.90 seconds
LSTM	0.91 seconds

5. Summary

Contributions

- UAV location indoor [a][b]
- Machine learning applied to navigation indoor

[a] J. P. Matos-Carvalho, R. Santos, S. Tomic and M. Beko, "GTRS-Based Algorithm for UAV Navigation in Indoor Environments Employing Range Measurements and Odometry," in IEEE Access, vol. 9, pp. 89120-89132, 2021, doi: 10.1109/ACCESS.2021.3089900.

[b] R. Santos, J. P. Matos-Carvalho, S. Tomic and M. Beko, "WLS Algorithm for UAV Navigation in Satellite-less Environments," under small revision in IET WSS.

Future work

- Obstacle avoidance
- Navigate the UAV without knowing the space
- Get to the destination without the intermediate points

Thank you for your attention!

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