Machine Learning-based Positioning using Multivariate Time Series Classification for Factory Environments

Nisal Hemadasa*, Marcus Venzke*, Volker Turau*, Yanqiu Huang~

* Hamburg University of Technology

~University of Twente

Content

- Introduction: Indoor Positioning Systems
- Motivation: Indoor Positioning in Industrial Logistic Processes
- Proposed approach and Contributions
- Results
- Conclusion

Indoor Positioning Systems (IPS)

- Widely adopted in:
  - Applications: manufacturing, logistics, sales, construction, etc.
  - Technological forefronts: Industry 4.0, Smart Cities, etc.
- GPS doesn't function indoors robustly
- Existing technologies
  - Technology-wise: RSSI, magnetic, sound, visible light, inertial navigation
- Further classification under,
  - Technique-wise: proximity, vision, triangulation, fingerprinting, dead-reckoning, collaborative sensing
  - Algorithm-wise: square method, maximum likelihood method, deterministic or probabilistic method

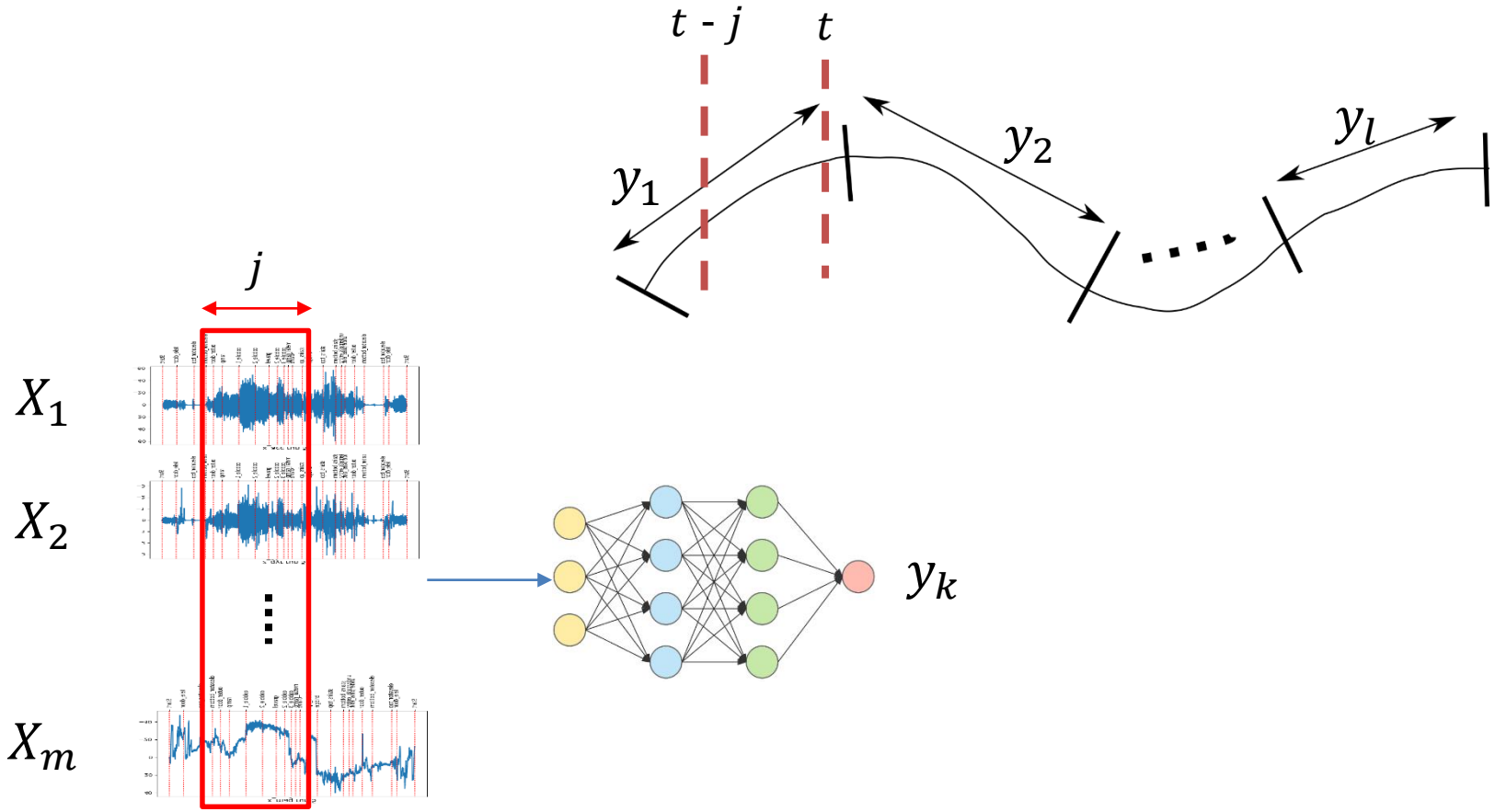
Positioning of Goods in Industrial Logistic Processes

- Could be defined as a sub-problem of Indoor Positioning: Involves transporting goods in well-defined paths, e.g.,
  - Factory assembly lines
  - Locations in warehouses
- X-Y coordinates are not necessarily required

Proposed Approach

- Inspiration: localization and navigation capabilities of higher animals
- Using embedded sensors, with machine learning, for low-cost, privacy secured increased, object localization in industrial logistics processes
- **Problem definition**: *Investigate the usage of,*
  - *Multivariate Time Series Classification (MTSC),*
  - *to find relative position of a know path in indoor environments,*
  - *using motion and ambience sensors, and*
  - *Machine Learning,*
  - *for low performance and low powered devices such as microcontrollers*

Factory IPS as a MTSC Problem



Advantages and Use-cases

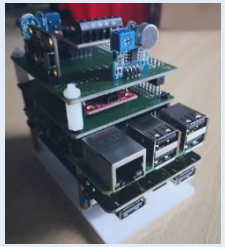
- Advantages:
  - No supplementary infrastructure needed (e.g., compared to RSSI-based methods),
  - Privacy secured (e.g., compared to vision-based),
  - No initial coordinates required and no accumulated error (e.g., compared to dead-reckoning),
  - Not based on assumptions (e.g., Gaussian noise and linear motion)

- Other possible application environments,
  - Tunnels,
  - Mining, etc.

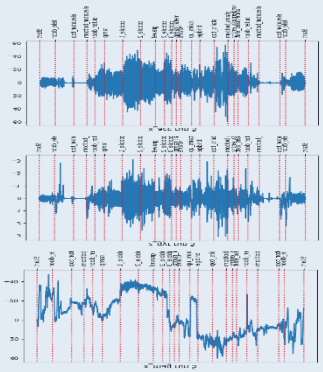
Contributions

- Compare,
  - potential ML models,
  - for MTSC for **motion-ambient dataset**,
  - targeting edge and tiny devices
- Models based on,
  - Multilayer Perceptron, Fully Convolutional Network (benchmarks for MTSC),
  - CNN-1D, CNN-2D (Variants of CNN and MLP)
  - LSTM, Bidirectional-LSTM (State of the art for high end edge devices),
  - Decision Trees, Random Forests (lightweight to fit MCUs)
- Criteria,
  - Accuracy,
  - Latency,
  - Memory Footprint
- Longer version of the paper in arxiv: https://doi.org/10.48550/arXiv.2308.11670

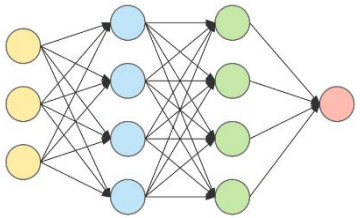
Proposed Solution: Overview



Data Collection



Data Preprocessing,
Feature Engineering

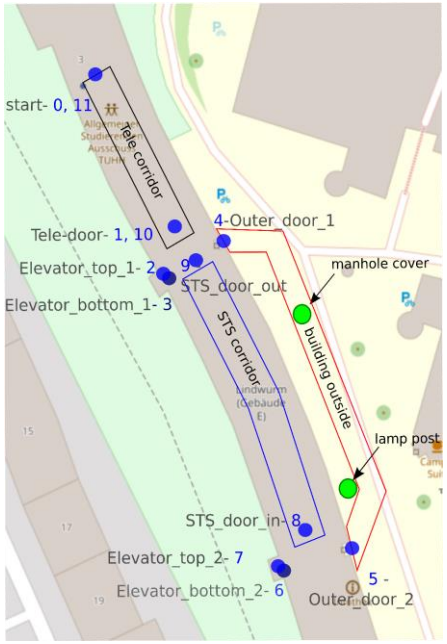


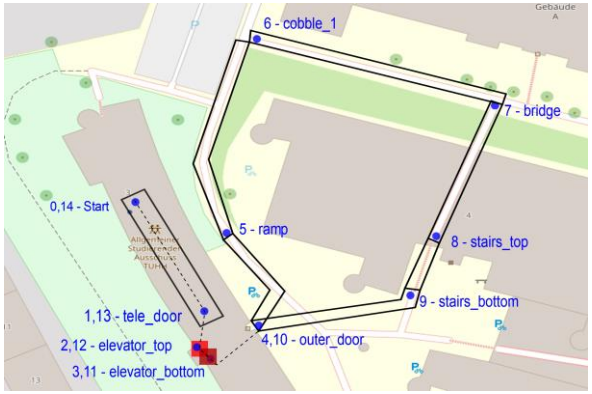
Training ML models

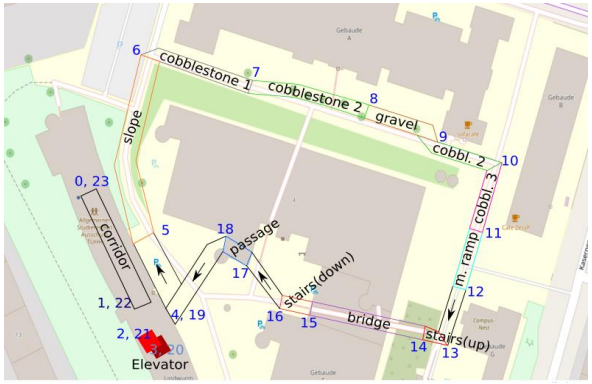
Motion-Ambient
Dataset

Motion-Ambient Dataset: Collection

- Three routes
- Path dynamics:
  - Indoors & outdoors
  - Stairs
  - Different terrains
  - Elevators
  - Ramps, etc.
- Include round trips







Motion-Ambient Dataset

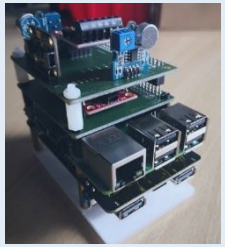
Sensor measurements:

IMU: (acceleration, rotation, mag. field)
Temperature
Humidity
Pressure
Spectrum

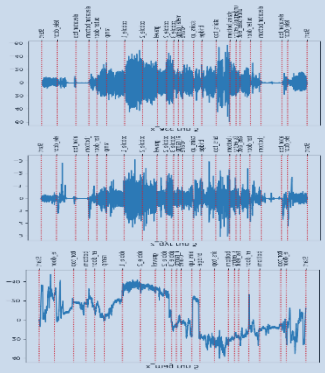
Route	Distance (m)	Rounds	Samples
1	470	115	1,597,657
2	233	180	1,439,903
3	327	115	1,597,657

Distances in km: ~135

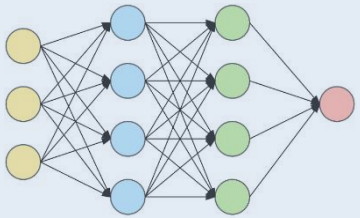
Proposed Solution: Overview



Data Collection



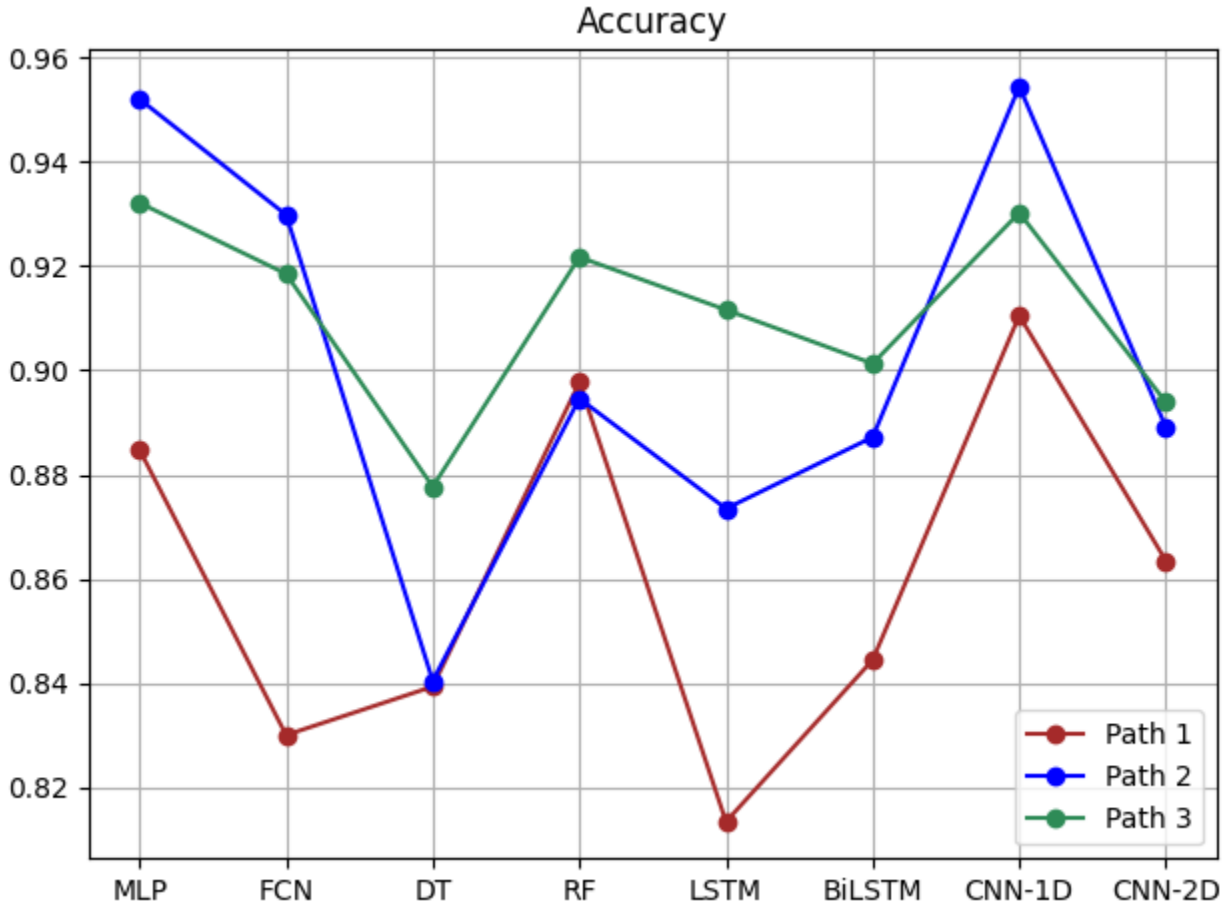
Data Preprocessing,
Feature Engineering



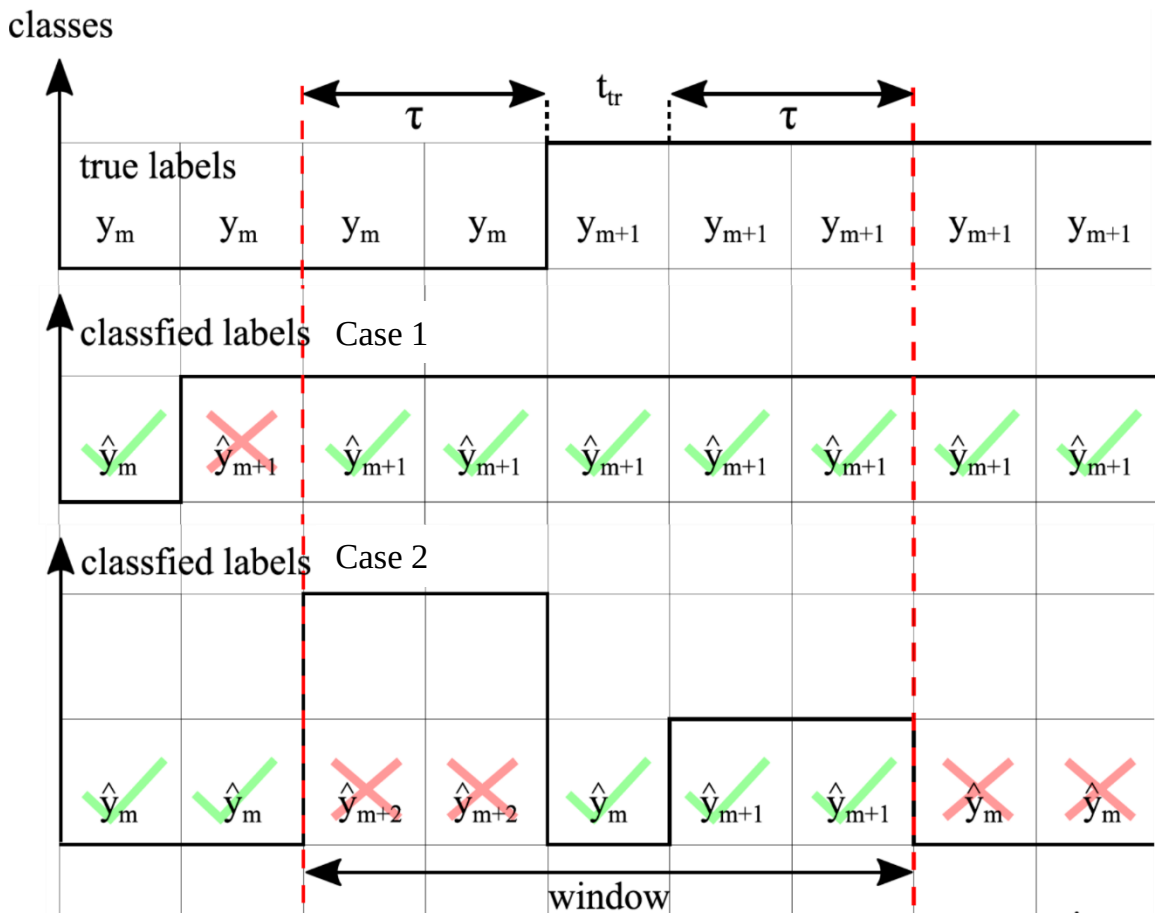
Training ML models

Motion-Ambient
Dataset

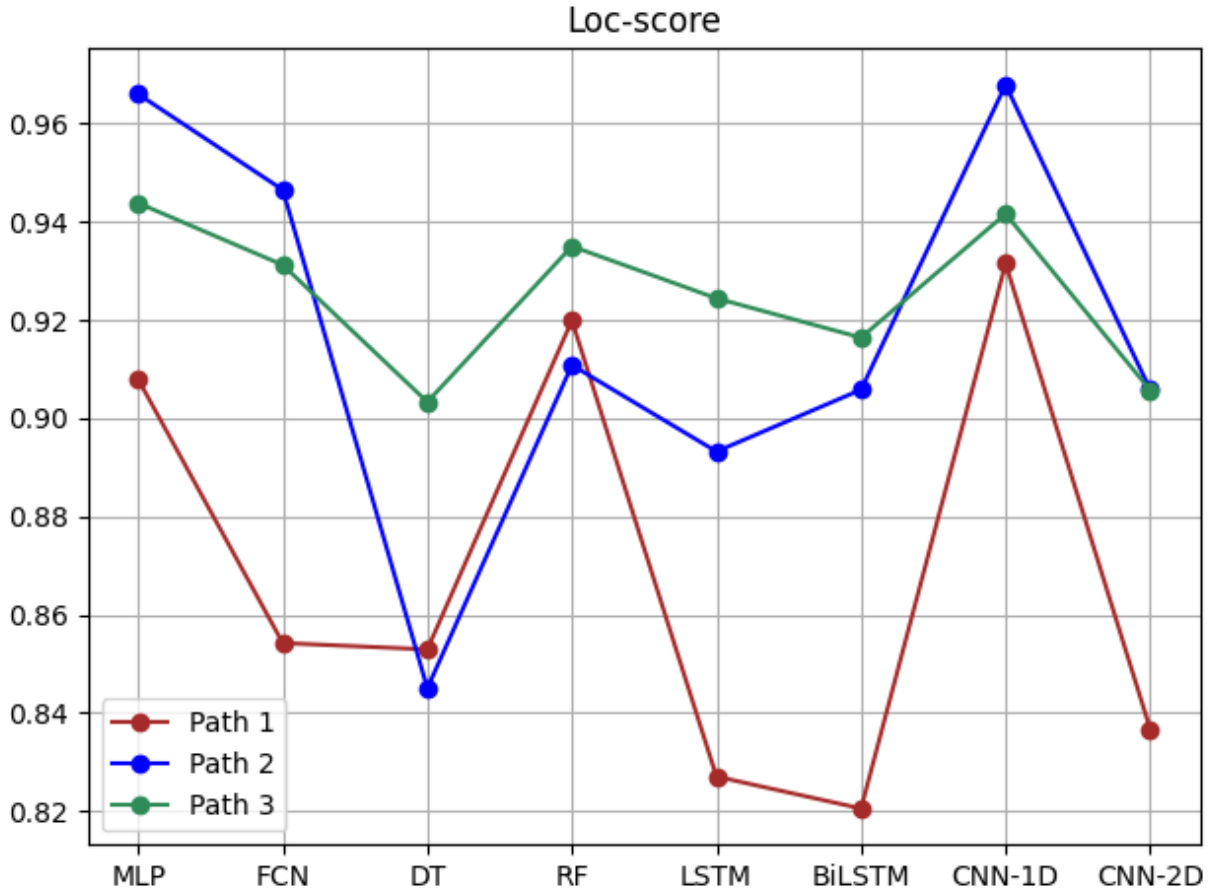
Results: Accuracy



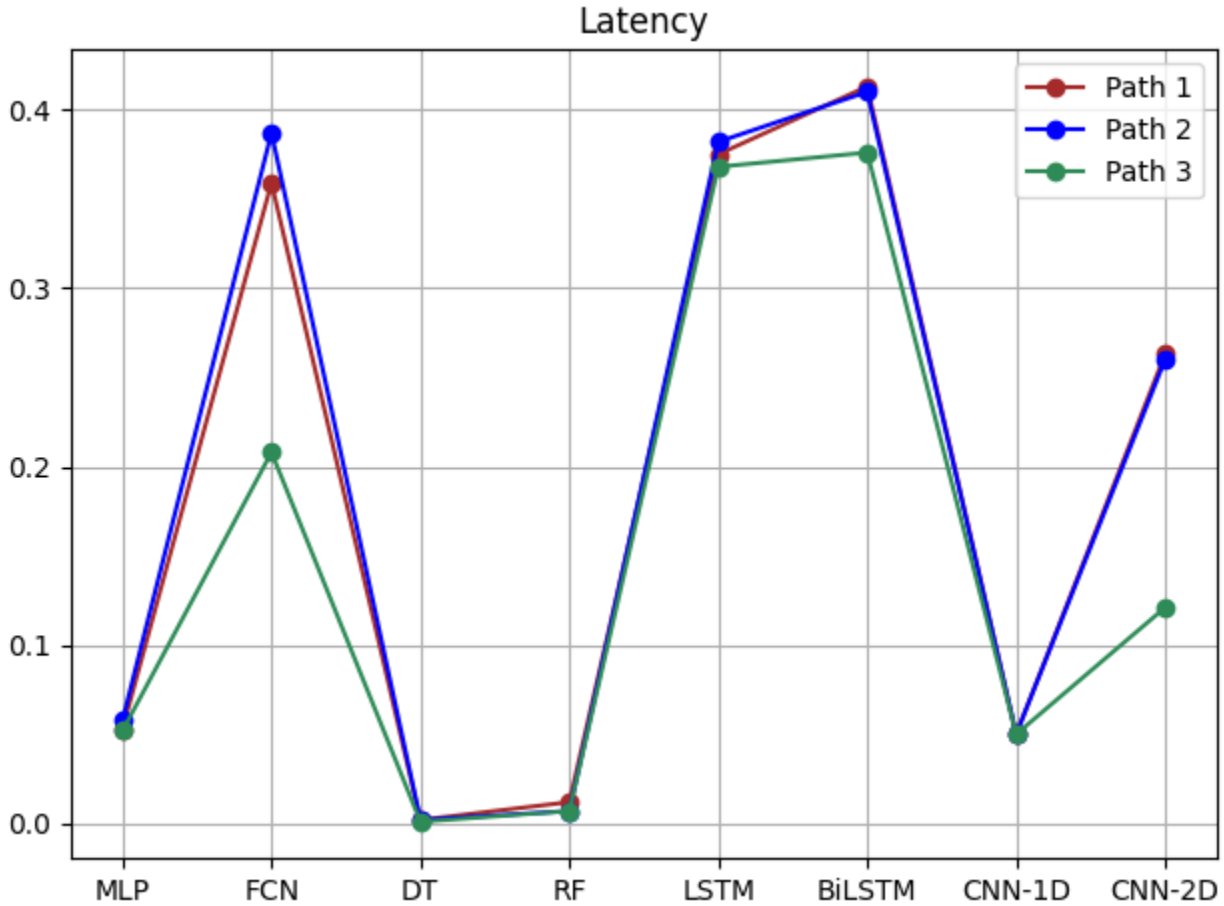
Definition: Loc-score



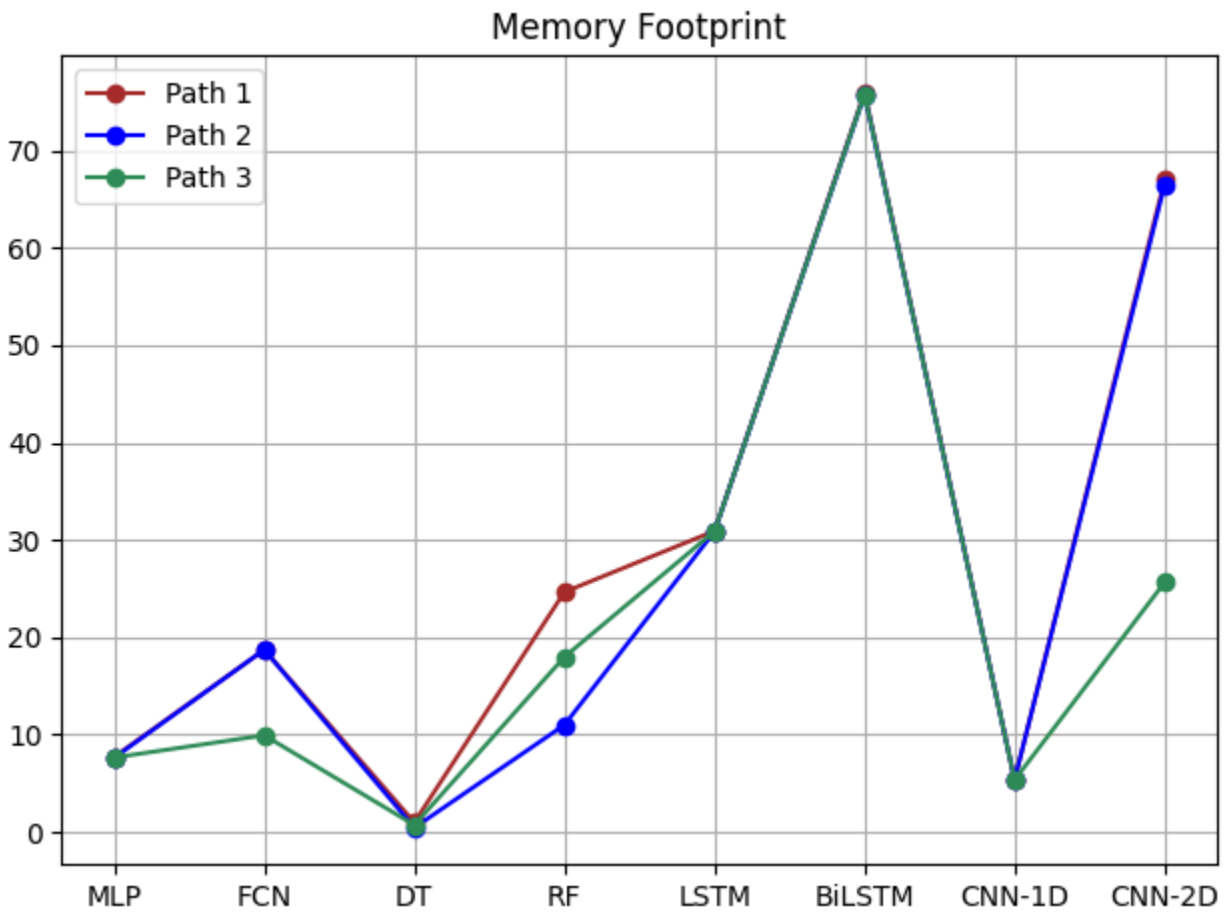
Results: Loc-score



Results: Latency



Results: Memory Footprint



Conclusion

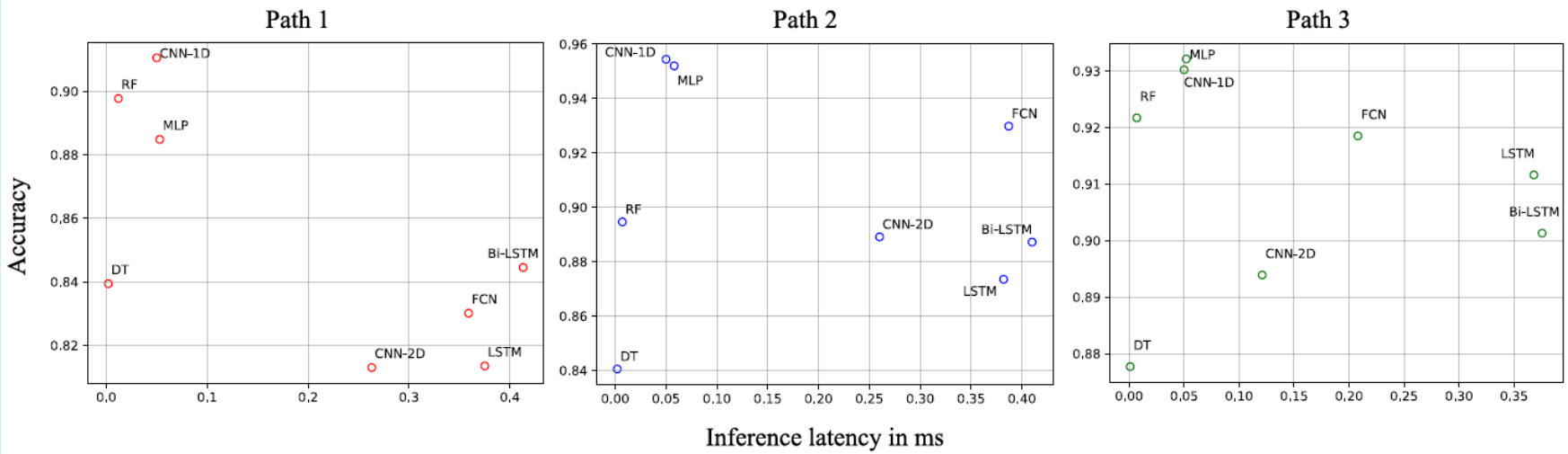
- Using MTSC to find relative position of a know path in indoor environments
- Investigated the usage of promising ML methods targeted for edge and tiny devices to solve MTSC using motion and ambience sensors
- Introduction of novel Motion-Ambient dataset

POWER | ENERGY | DATA | CYBERSECURITY | AI | PROCESS | CLOUD

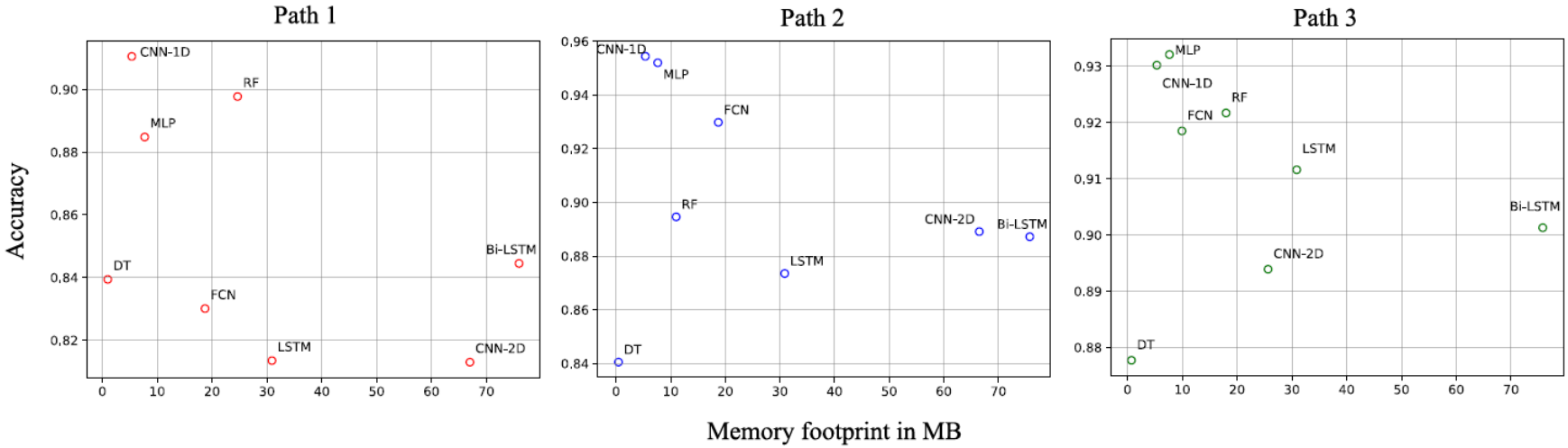
SOFTWARE | ECOMMERCE | HPC | HEALTH IT | ELEARNING | AI

Thank you

Results: Accuracy vs Latency



Results: Accuracy vs Memory footprint



Results: Memory footprint vs Latency