Spatial-temporal Traceability for Cyber-Physical Industry 4.0 Systems

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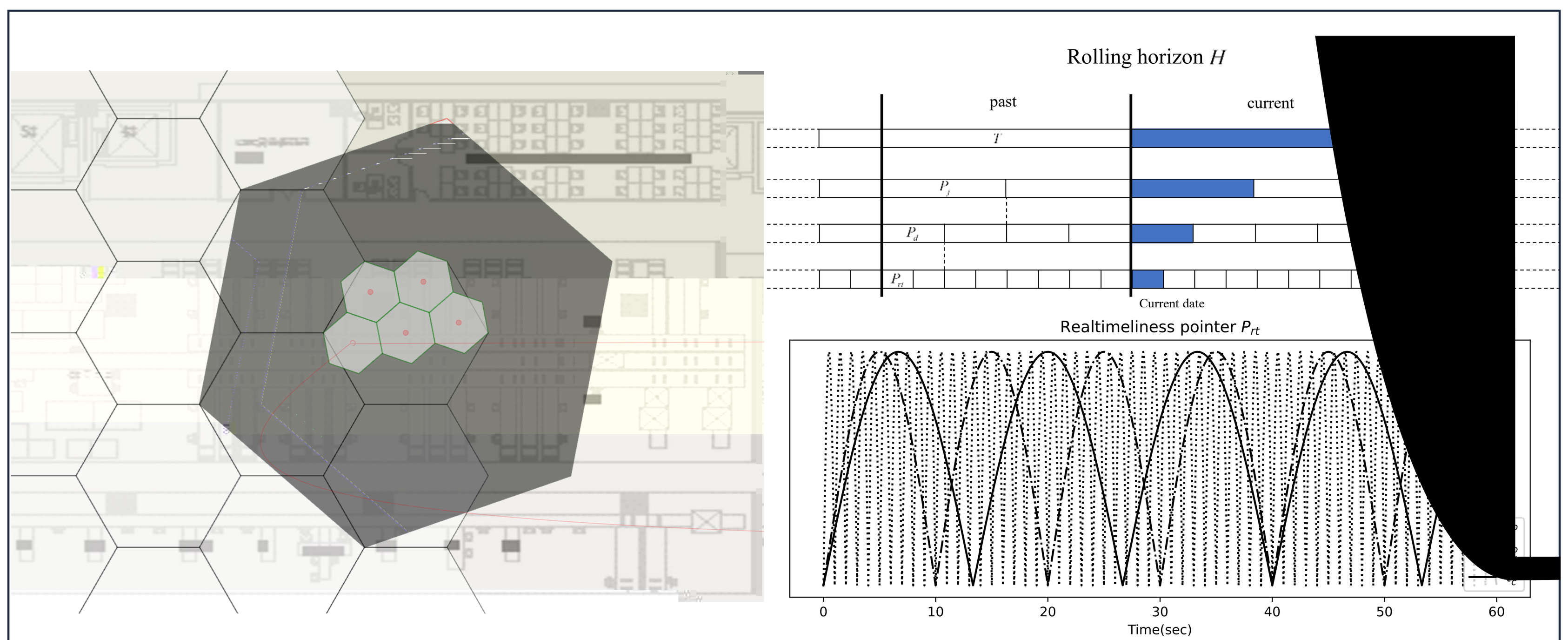
Introduction

In this research, we first delineate and propose universal and interoperable spatial-temporal elements for cyber-physical industrial 4.0 systems (CPIS). A multi-modal bionic learning method for indoor positioning is developed to estimate the accurate and reliable location in a durable manner. Proximity, mobility, and contextual reasoning mechanisms are introduced to capture interplay, evolution, and synchronization among objects at operational level. To verify and evaluate the efficacy of our proposed solution, we implement it in a real-life case company and conduct a comparison study. Our results indicate that the proposed method outperforms the current indoor positioning methods and represents a significant step forward in achieving spatial-temporal traceability in CPIS.

Research Questions

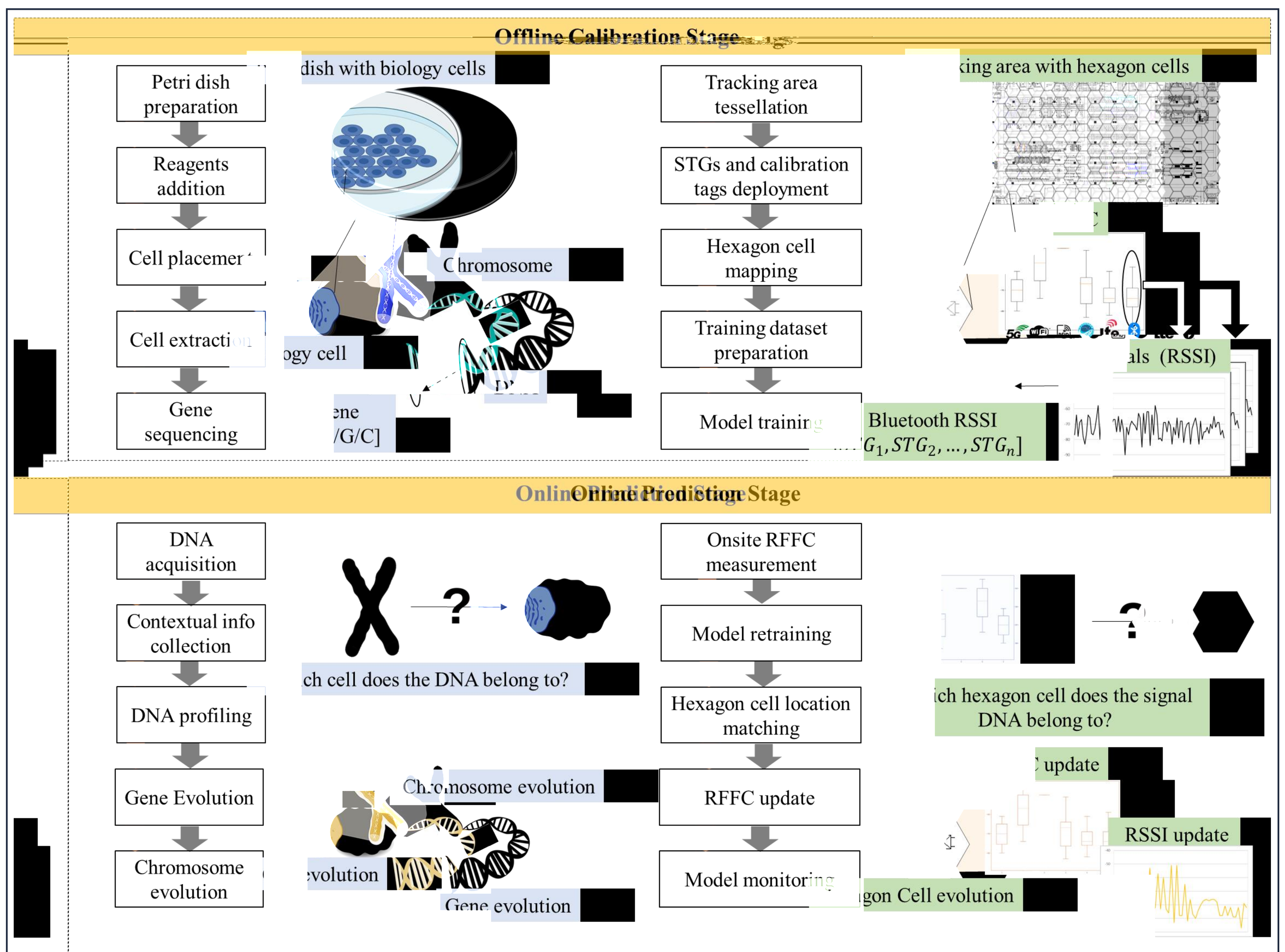
(1) What is the most suitable representation standard to fulfil shared and interoperable spatial-temporal traceability considering objects shuttling between indoor and outdoor?
(2) How to realize accurate and reliable indoor positioning in a durable manner through multi-modal data from CIPS?
(3) How to manipulate spatial-temporal data through reasoning mechanism for supporting operation-related decision-making?

Spatial-temporal Elements in CIPS



We blend self-contained coordinate system into the H3 model with extra height indicators. The coordinate system is direct representation of positioning results in limited indoor environments. We first map the coordinates derived from indoor positioning results to the H3 hexagon cells at we blend self-contained coordinate system into the H3 model with extra height indicators. The coordinate system is direct representation of positioning results in limited indoor environments. We first map the coordinates derived from indoor positioning results to the H3 hexagon cells at predefined resolution levels according to positioning accuracy requirements. The hexagon cells are like exact IP address in the computer networks where subnet mask implies higher level area. Then, we label the hexagon cells that tessellate in the same level of the building with height labelling. predefined resolution levels according to positioning accuracy requirements. The hexagon cells are like exact IP address in the computer networks where subnet mask implies higher level area. Then, we label the hexagon cells that tessellate in the same level of the building with height labelling.

Multi-modal Bionic Learning for IPS



The Figure showcases the overall process of MMBL in the light of biological cell evolution. The left side of this figure tells the story of how the biology cell is cultivated, extracted, judged, and evolved, while the right side depicts the corresponding process implemented in the hexagon cell localization. MMBL consists of two stages, which are offline calibration stage and online prediction stage.

Case Study and Conclusions

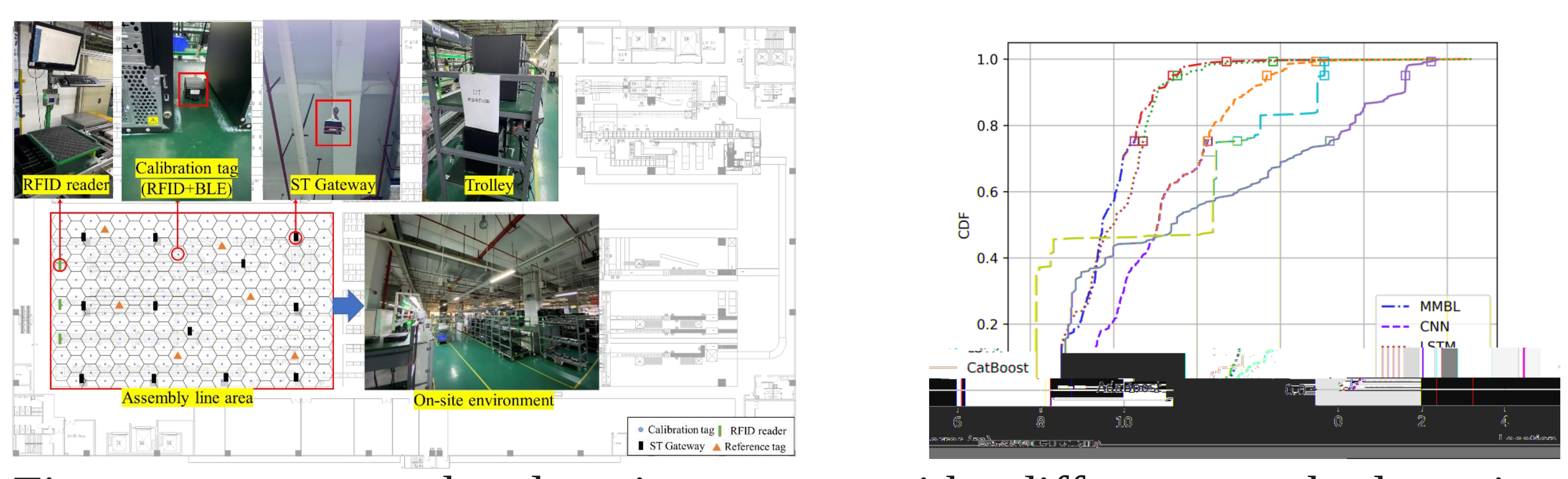


Figure compares the location error with different methods using cumulative distribution function. In the figure, MMBL clearly outperforms the other methods with 95% of the errors are within 3.41m, which is lower than CNN (5.67m), LSTM (3.53m), and other gradient boosting methods. The 99% errors of MMBL are within 4.70m in the industrial settings. From the above result, the MMBL has a good anti-interference ability to instable RRFC.

This research delineate and compare basic spatial-temporal elements for geospatial traceability both in indoor and outdoor settings. A multi-modal bionic learning method is the proposed to realize accurate and reliable indoor positioning as analogous to the biology cell evolution and mutation. Three types of spatial-temporal reasoning mechanisms are put forward to generate insights and predictions entailing intelligent decision-making.

Acknowledgements

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