A Conceptual Digital Twin for 5G Indoor Navigation

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Introduction

- The focus of this research is on indoor navigation based on the **Digital Twin (DT)** paradigm.

- The use of a DT requires access to various data sources related to the specific lifecycle stage of the building.

- For Facility Management (FM) applications, historical and current data sources are needed in order to perform key analytics and generate results for furthering FM stakeholder engagement.

- Additionally, future states also need to be predicted (from 5G and sensor data).

The Digital Twin Paradigm

- The generation of up-to-date digital representations of buildings, specifically using BIM, is an expensive, time consuming and cumbersome process - largely tied to monolithic software systems.

- Combination of additional data sources e.g., IoT or existing digital documentation is often excluded.

- For use in Facility Management of current and future smart buildings, a centralized and automated approach for processing and analysis of data is required.

- A Digital Twin is a cyberphysical representation of a physical object (e.g., a building), that can be used to assess and forecast its former, current and future states based on analysis of related data.

Level 5 Indoor Navigation Project

- A 5G Non-Standalone (5G NSA) campus network and an additional experimental system will be realized at the main HafenCity University Hamburg building location between Q3 2021 and Q1 2022.

- Applications from the field of indoor navigation will be tested there and will serve research purposes.

- The planned campus network will consist of four outdoor antennas arranged around the main university building.

- For the planned outdoor and indoor network, the use of private frequencies in band B43/N78 (3.7–3.8 GHz) with a LTE anchor band is planned.

- The project will also set up a second experimental network, with frequencies in the range of 26 GHz–78 GHz to achieve even higher accuracy for the estimation of the position.

- Indoor units will also be provided on two floors of the building.

Problem Statement and Proposed Solution

- Determining the optimal route to get between two points is often a bottleneck for FM tasks.

- Solving such a problem requires the approximation of the user’s current location within a building as well as the approximate location of the destination point.

- One key approach to solving this problem is based using autonomous localization methods.

- The use of 5G infrastructure and technology could increase the accuracy of indoor navigation applications.

Approach

- The use of a service-oriented computation enables the design and deployment of complex software components and services.
- Such services are capable of meeting the requirements of accessing, storing and processing versatile data sources.
- Additional benefit of hardware decoupling is also present.
- SOS implementations can process and stream specific results related to FM activity to a variety of client devices.
Capture of Indoor Environments

- Point clouds enable the capture and representation of the as-is state of the built environment.

- Terrestrial laser scanning (TLS) is a well-known technique in BIM surveying - captures the reality by using the reflection of laser light.

- Methods: time of flight, phase shift and triangulation

- Measurements:
  - Horizontal angle
  - Vertical angle
  - Distance

- Output:
  - 3D point cloud (XYZI + RGB)
Simulation of Point Cloud Capture

- The simulation of LiDAR can also be implemented in software.

- If LiDAR equipment is not available or costly to use, the approach of synthetic point cloud generation can be applied.

- With this approach, a higher-level geometric representation (e.g., a 3D mesh), is used to simulate the process of point cloud scanning.

- Simulation of laser beams hitting a surface is accomplished by projecting rays into a 3D mesh and sampling the intersecting points.


Blensor - https://www.blensor.org/pages/tutorials.html
Point Cloud Processing and Semantic Enrichment

- Raw point cloud data must be pre-processed prior to reconstruction and semantic-enrichment.
- Objective is to optimize complexity, while preserving key visual fidelity features.
- Point clouds do not contain any semantics default - therefore semantics need to be added manually or automatically.
- Automated methods rely on supervised deep-learning (e.g., use of 2D/3D CNNs) to add semantic labels to point clusters.
- Semantically-rich point clouds can then be used for generating higher-level representations e.g., as-is BIM data.

Database Integration

- A relational or non-relational DBMS can be used, with additional special spatial indexing operations.

- Use case: Quickly access point cloud, CAD or BIM representations of e.g., entire floors or specific rooms of a building, for processing and analysis.

- This also allows for the integration of point clouds with additional static (e.g., IFC models), and spatio-temporal data sources (e.g., sensor data).

- PostgreSQL DBMS is used as object-relational DBMS, along with its spatial database extension PostGIS.

- Such DBMS it provide support for georeferenced objects that enable spatial queries.
Localization Methods within 5G Paradigm

- To approximate the user’s initial location, different absolute positioning algorithms (e.g., triangulation, trilateration and multilateration), can be used to determine the approximate location of the user.

- User’s current location can be estimated based on the fusion of the maps information, routing graphs, the absolute positions and the received sensor data readings.

- Use of state estimation algorithms is required for this (e.g., Monte Carlo Particle Filtering or Extended Kalman Filtering).

- Within the 5G paradigm, user’s mobile devices can capture and process localization data, as well as provide additional sensor data output such as barometer readings.

Representation and Interactive Visualization

- Visualization of key data sources is enabled using real-time 3D rendering.

- Can be implemented using existing game engines (e.g., Unity) or Web3D frameworks (e.g., Three.js)

- All related data e.g., point cloud, BIMs, CAD drawing, floor plans, etc, can be visualized individually or simultaneously.

- Viewing in 2D or 3D allows for inspection of areas of interest, and running on different client devices.

- Using an SOS implementation, key results can be computed on server and sent to client for visualization.

- The use of interactive visualization enables for enhanced decision making amongst FM stakeholders.

Prototypical System Design and Implementation

Experimental Results - Point Cloud Processing

- The point cloud of the fourth floor area of the university building is generated using simulated laser scanning.

- We make use of the as-is BIM at LOD 300, from which we extract a triangulated mesh and sample points.

- Once generated, further processing is performed (e.g., sub-sampling, outlier point removal and segmentation).

- The result of these processes are point clusters representing key structural elements which can be used as floor plan layers.

A key requirement of indoor navigation is the determination of navigable areas.

A common name for data structures used to represent such navigable areas are “routing graphs”.

The use of routing graphs is therefore a requirement for pedestrian indoor navigation, especially for approximation of optimal paths.

A 2D floor plan can be generated either from the existing as-is BIM, or from the as-is point cloud representation.

By applying spatial analysis methods, the 2D floor plan can be used to approximate routing graphs.

Once geo-referenced, the floor plan and the routing graph can be utilized by positioning algorithms to approximate the current location.

Experimental Results - Shortest Path Approximation

- The shortest path generation is performed using the generated routing graphs.

- For routing graph generation of 2D floor plans, we make use of a generalized Voronoi-based medial axis transform.

- For routing graph generation from the as-is BIM model, we use the triangulated mesh of the floor element boundary representation.

- For computation of the shortest paths using routing graphs, we make use of the A* shortest path algorithm.

- The generated shortest path computation allows the user to select and set starting and ending points, between which the shortest path will be computed.

Experimental Results - 5G Simulation and Localization

- Using the Simulated 5G Capture components, the antenna placement and three 5G positioning signals are simulated.

- This is calculated based on some reference points and given noise.

- In this way, one may simulate 5G-based coordinates with different precision.

- This is needed for fusion algorithms when such a simulated infrastructure-based positioning has a high range of noise.

- The number of desired antennas and positions can be set and by calling a calculation function, the predefined noises, frequencies and some measurement results can be computed.
Conclusions and Outlook

- We have proposed our approach based on a concept of a Digital Twin.
- We have implemented key processing components to prove the feasibility of such an approach.
- The use of service-oriented software engineering allows for flexible implementation of key processing components, and delivery of results to various client configurations.
- We have identified the use of point clouds as a key source for as-is representation of indoor environments, alongside existing as-is/as-built BIM data.
- We approximated 2D floor plans from point clouds, and the generation of routing graphs from such floor plans as well as 3D mesh representations derived from existing as-is BIMs.
- We have designed a simulation for 5G-based coordinate estimation to overcome with the localization task.
- We have implemented and described state-of-the-art approaches for routing graph and optimal path computation.
- The presented approach lays a solid foundation for future work focusing on developing a versatile indoor navigation software solution based on the DT and service-oriented computing paradigms.

Thank you for listening!

Level 5 Indoor Navigation Project
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