Movement Behavior Analysis of Workers using Spatio-temporal Trajectories for Safety Management

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Extended Abstract. Occupants` movements and presence are fundamental and the pre-requisite for any type of occupant behaviors` understanding for safety management in buildings which tells whether a building location is occupied, the number of occupants or an occupant with a specific profile in a certain location (Arslan et al. 2019). Numerous studies have been conducted over the past few decades to model occupant behaviors stochastically for an improved understanding of their activities for different safety management applications (Hong et al. 2015; Yan et al. 2015). Despite many research efforts to model dynamic behaviors of building occupants, there is still a gap exists in understanding their behaviors in the context of dynamic building environments (Arslan et al. 2019). The contextual data linked to locations in dynamic environments evolve often over time in terms of position, size, properties and relationships with the environment (Cruz 2017). This changing building environment effects the occupants` movements and presence inside the facility which ultimately degrades the process of inferring their accurate activities based on the location context. Henceforth, the evolving building information is required to be mapped with occupant movements for an improved understanding of their changing behaviors for safety management applications. To fill this research gap, a framework named 'Occupant Behaviors in Dynamic Environments' (OBiDE) is designed for providing a 'blueprint map' to integrate existing DNAS (Drivers, Needs, Systems, Actions) model (i.e. a scheme to model occupant behaviors) with our STriDE (Semantic Trajectories in Dynamic Environments) data model to include the dynamicity of building locations for an improved understanding of occupant behaviors for safety management. The proposed framework extends the usability of DNAS (Hong et al. 2015) by providing a centralized knowledge base that holds the movements of occupants with relevant historicized contextual information of the

building environment to study occupant behaviors for different facility management applications. The proposed framework (see Fig. 1) requires sensory data to include context to occupant movements and presence for performing behavioral analysis. The acquisition of relevant sensor data is based on the application requirement. For instance, the safety manager of a building requires to monitor the movements of the occupants in a building. In this case, using our OBiDE framework, 'driver' is monitoring movements of occupants, 'need' is achieving safety management in a building by identifying unsafe movements, 'action' is tracking movements of occupants using their spatio-temporal trajectories, 'system' corresponds to Bluetooth Low Energy (BLE) beacons for sensor data acquisition deployed in a building and 'states' are 1) static (no movement), 2) normal movement ($0 < \text{steps} \leq 84$ and $\pi/2 \leq \text{angle} < \pi$) and 3) risky/unsafe ($\text{steps} > 84$ $\text{angle} \geq \pi$). Existing literature (Arslan et al. 2019) suggests that the movement behavior of an occupant is defined using step length and turning angle. The average walking speed of a person range from 1.0 to 1.6 meters per second (m/s). Keeping an indoor environment into account, a value of 1.4 m/s as a safe walking speed limit that will give us 84 steps per minute i.e. the sum of step lengths for a minute. For understanding movement-based behaviors for a safety management application, around 200 BLE beacons are installed on different building locations. Approximately 13,223 location coordinates are collected across different locations using deployed beacons. After sensor data acquisition, the acquired location data is transformed into trajectories after preprocessing (i.e. filtering). More information on trajectories and their preprocessing can be found in (Zheng 2015). After preprocessing the trajectories, the STriDE model (Cruz 2017) is used to add contextual information of a building environment in collected trajectories for mapping actual building locations with each trajectory point. For tracking the evolution of building objects (occupants, trajectories and locations), the STriDE model uses the concept of timeslices (TSs). For modeling the behaviors to recognize and categorize the movements into different states, many types of non-probabilistic and probabilistic approaches exist in the literature such as Bayesian dynamic models and clustering techniques, state-based models such as simple Markov chains and HMMs, patterns matching algorithms and deep learning-based techniques (Arslan et al. 2019). Though, HMMs-based method is selected for our application as statistical HMMs describe occupant movements as a series of Markovian stochastic processes where the probability distribution of a future state (i.e. safe or unsafe behavior or a next location) of a stochastic (i.e. a random) process (a trajectory in our case) is only dependent on its

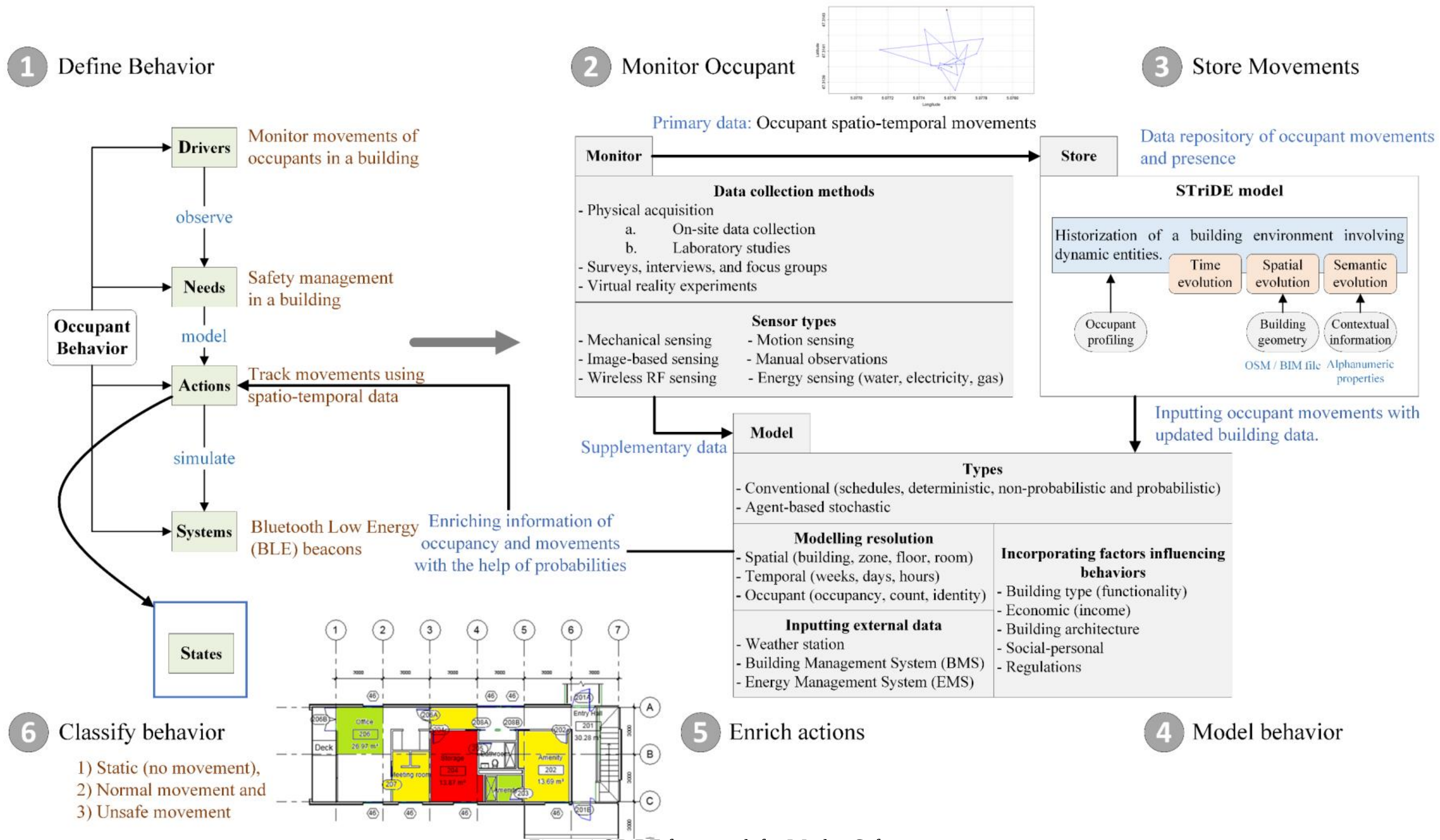

Figure 1 OBiDE framework for Worker Safety

current state or a current location which disregards the requirements of including the preceding states and ultimately minimal training data is required (Arslan et al. 2019). For inputting the movement states into HMMs, Gamma distribution for step lengths and Von Mises distribution (also known as the circular normal distribution) for turning angles are used. After describing the states, a Baum-Welch algorithm with Viterbi algorithm is used to extract most probable movement states across each building location. For visualizing the states resulted from HMMs, BIM-based software i.e. Revit Architecture is used. No movements but presence is shown in Green, normal movements are in Yellow and risky movements in Red color in different building locations. The BIM approach is selected because existing literature recognizes it as a 'future IT solution' and favored over traditional 3D CAD approaches as it is an efficient way of information management during the building lifecycle (Arslan et al. 2019).

Keywords: Behaviors, Safety, Construction, BIM.

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