HumanS: A Human Mobility Sensing Simulator

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***Abstract*—In this paper, we propose a human mobility sensing system simulator called HumanS. HumanS is a multi-agent simulator that works with geographic information system (GIS). It models realistic movement of pedestrians and behavior of sensors that capture the mobility. Developers can evaluate performance of such sensing systems that detect location of people for pedestrian navigation, purchasing behavior analysis and so on under realistic model of environment. The simulator is designed based on GIS databases that store and manage the scanning data by appropriately tagging their time and location. The capability of the HumanS simulator has been validated by a scenario where accuracy of a pedestrian flow sensing system is tested with different settings of sensor types and location in Osaka downtown.**

***Index Terms*—GIS, System Evaluation, Urban Environment, Mobility Modeling, Sensor Modeling**

I. Introduction

Location information about people can be utilized for pedestrian navigation in different situations (in very crowded events, emergency case etc). Lights and air conditions in buildings can be controlled for more efficient energy management based on detailed information about people's indoor location. In these systems, sensors such as laser-range scanners and image sensors are installed to some places to monitor people and surroundings, and the choice of sensor location, the number of sensors, and their performance will greatly affect the performance of the target systems. However, to find such a property, a number of experiments are necessary in the real world, which needs considerable effort.

In this paper, we propose a human mobility sensing system simulator called HumanS. HumanS is a multi-agent simulator that works with geographic information system (GIS), and has the following features. First, it models realistic behavior of pedestrians (human agents), where modeling accuracy has a significant impact on the performance of such sensing systems. The simulator automatically calculates the possible paths from given indoor/outdoor maps as shown in Fig. 1 and then determines the paths of human agents from given origin-destination flow information. The simulator provides several sensor models and the sensor agents can be placed on any location in given GIS maps to detect the presence of human agents in the sensing area. A sensor model is specified by scan range, scan angles, and scan intervals, as well as scan blocking conditions that are directly related with sensor detection errors. The simulator stores and manages the scanning data in a GIS database by appropriately tagging their time and location.

Fig. 1. Screenshot of HumanS simulator

Therefore spatial and temporal queries, which are needed in sensor data analysis, can be processed in an efficient way. The simulator visualizes sensor location, sensing regions and human location on GIS map, which helps intuitive awareness, recognition and analysis of events in the simulation, such as miscount of people in some crowded regions.

We have synthesized realistic movement of human agents in the underground city of Osaka downtown [1] based on the real population data [2]. Then using our sensor model of laser-range scanners, the pedestrian flow estimation method [3] has been simulated to test its performance. We have verified that different types, placement and number of sensors resulted in different performance, and have confirmed that such assessment can be done in a more efficient way than field experiments.

II. Related Work

Wireless sensor networks have had a lot of attentions for physical world event sensing. However, since their installation in real environments needs much effort, a variety of simulators for WSNs such as NetTopo [4], ATEMU [5] and Avrora [6], have been developed so far. Since these simulators mainly focus on simulating or emulating sensor node architecture such as memory, batteries, wireless transmission and protocols, they are not interested in simulating the behavior of sensing activity. Although some researches such as [7] focus on modeling and

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simulation of sensors, the emulated outputs are not the capture of "real world" but are synthetic. Therefore, it is not possible to examine how sensor capability such as sensing accuracy and sensor types affect the performance of target systems.

Some simulators and approaches have been proposed to model urban environment and mobility. UrbanSim [8] is designed to simulate whole cities where people and vehicles are moving around. LEAM [9] is the Land Use Evolution and Impact Assessment Model that has been designed to simulate land use planning. City simulators are usually multi-agent simulators, and these are aimed at representing large-scale urban scenarios such as metropolitan planning and transportation planning. Recent work on urban environment simulation framework [10] has considered sensing data, but it has been designed for dedicated purpose. GIS has been used not only for geography-related spatial information but also for simulating phenomenon in real environments. Most of those systems aim at assessing affect of disasters on people and environment, for urban planning and evacuation planning [11]. In Ref. [12], Hollick et al. propose a macroscopic mobility model for wireless metropolitan area networks, where multiple zones such as workplace, commercial and recreation zones are considered.

Our contributions are two-fold. Firstly, our HumanS simulator has been designed with a new idea of simulating both (i) mobility of people in cities and (ii) input and output of sensors that capture the mobility on GIS data. Therefore, it is possible to evaluate such a system that captures location and mobility of people and analyzes them. Secondly, we fully utilize GIS databases to manage sensing events as well as simulated objects and regions. Thus developers can be beneficial from our simulator design since they can access everything observed in simulations via well-familiar database queries. To the best of our knowledge, no previous simulators have considered evaluation of such human mobility sensing systems in a realistic and efficient way.

III. Design of HumanS simulator

A scenario for HumanS is given as (i) a map data, (ii) human agent information, (iii) sensor information and (iv) network information. A map data is given as the SHAPE format. On the given map, a set of origin and destination points should also be given, and a set of flows, each of which consists of origin and destination points and a flow rate (a human agent generation rate). Each sensor is specified as a tuple of sensor type, sensor location (3-dimensional coordinates and direction on the map), and some performance parameters that are associated with the sensor type. If a target system is composed of wireless networks such as ad-hoc networks and is needed to evaluate the network behavior, the network information can also be given as a part of the scenario.

Fig. 2 describes the basic architecture of HumanS that consists of a GIS database, GUIs output visualization and the core simulation engines. For the GIS database part, we have used PostGIS [13], which is additional software to handle

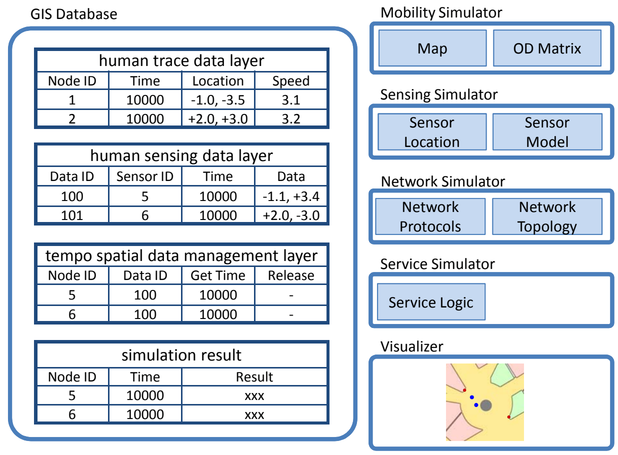


Fig. 2. Architecture of HumanS simulator

geography-dependent data in PostgreSQL. The mobility simulator part simulates human movement, and the human agent trace data (ground truth) are stored to the "human trace data layer" in the GIS database. Then the sensing simulator part reads these trace data according to the capability of sensors, and these sensor readings are stored to the "human sensing data layer" in the GIS database. Simultaneously, the network simulator part (this is currently optional) simulates network systems and data delivery, and based on the simulation results, "tempospatial data management layer" in the GIS database is updated. Services and systems to be examined can be implemented in the service simulator part, which accesses the tempospatial data management layer. Finally, the simulation results are visualized as shown in Fig. 1.

A. Mobility Simulation

The mobility simulator part has several features to realize realistic mobility. The target area is specified by a digital map in the ESRI shape format like Fig. 1. We may prevent human agents from going into some sub-areas. These restricted areas are called restricted zones and others are called free zones. An origin-destination matrix is assumed to be given and each element in this matrix represents the number of nodes moving from the origin and toward the destination per unit time.

On the way from an origin to a destination, nodes may pass through several "waypoints", which are automatically determined by analyzing the GIS map data. The mobility simulator chooses these waypoints for each node so that the node does not enter restricted zones and does not collide against other nodes. To implement this behavior, free zones in the map are divided into triangles and routes are determined as a sequence of these triangles. Since these triangles are in the free zones, the nodes can always move within the free zones. In addition, when a node passes a triangle, entrance and exit points of the triangle are chosen for the node, where the trace does not cross the other nodes' traces in the triangles. Also, we have implemented such a function that simulates movement delay caused by crowds. In the HumanS simulator, node speed is dynamically and automatically adjusted according to the node density. Due to these features, the HumanS simulator can easily represent realistic mobility. We note that node locations are updated every 200 ms in the current configuration.

B. Sensing Simulation

The sensing simulator part simulates the behavior of installed sensors that capture node locations according to the sensor capability. At first, the sensors are located on the map according to a given simulation scenario. These sensors can detect the presence of nodes only when the nodes are in their scan ranges. Given human trace data (ground truth) that have already been generated in the GIS database (by the mobility simulator part) and sensor capabilities such as scan ranges and detection ratios, the sensing simulator part calculates the nodes that are supposed to be detected by these sensors and stores the results to the human sensing data layer. We note that scan ranges are defined by the capability of the sensors. For example, for infra-red based position sensitive detectors, lines are used to represent scan range where pedestrians who cross the lines are detected. Laser-range scanners can detect nodes in fan-shaped scan regions by laser light and can continuously measure nodes' locations periodically. These sensing data (detected/measured human traces) are stored into the human sensing data layer. In order to simulate sensor behavior more accurately, we may set detection miss ratio functions, which take distance to nodes or node-density as an input.

C. Network and Service Simulation

The HumanS simulator also assumes a network simulator part, which can be an external module such as an existing network simulator. HumanS manages only data delivery that occurs among agents (humans and network components such as servers) over wired/wireless networks (i.e., L7 communication only). The external network simulator manages underlying layers (L4 and below), and thus the types of networks which we may simulate depend on its capability. When a request to deliver data is issued by an agent in HumanS, it is notified to the external network simulator with the up-to-date location of agents and the corresponding network simulation is conducted. The result (success or failure of data delivery) is fed back to HumanS and the "tempospatial data management layer", which maintains the time and location of application data, is updated. We note that the external simulator may explicitly access the GIS database to progress internal network simulations (like routing update in L3 etc). A service to be examined by the HumanS simulator is a function that accesses application data in the "tempospatial data management layer", and returns calculation results.

TABLE I
DENSITY VS. DETECTION RATIO IN LRS MODEL

Density ($persons/m^2$)	Detection Ratio
0.016	0.948
0.056	0.887
0.122	0.787
0.242	0.649

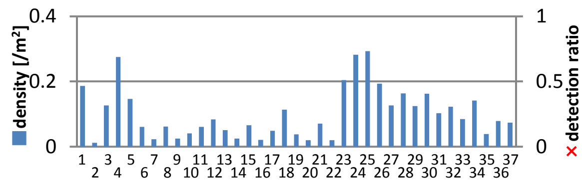
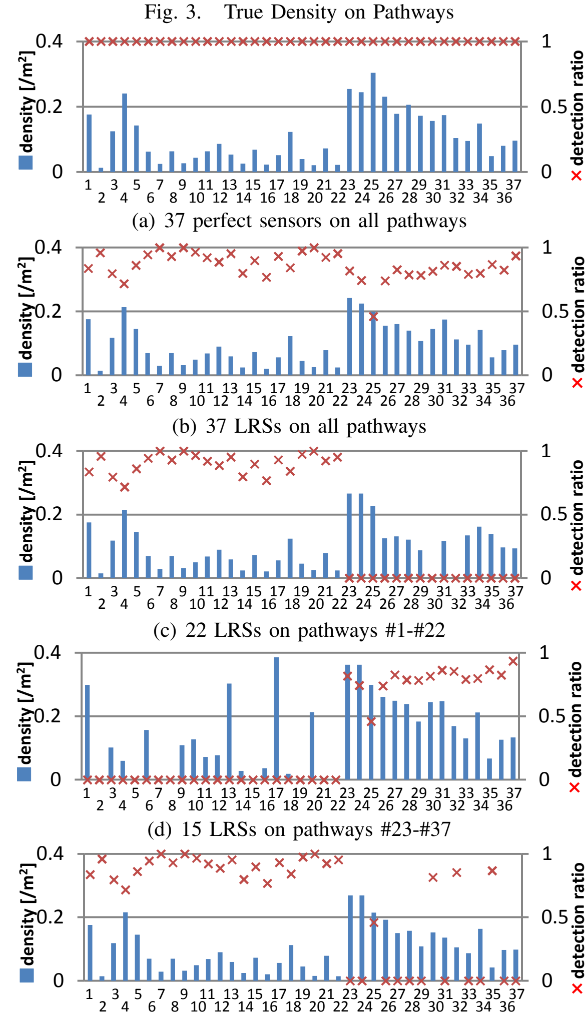


Fig. 3. True Density on Pathways



(a) 37 perfect sensors on all pathways
(b) 37 LRSs on all pathways
(c) 22 LRSs on pathways #1-#22
(d) 15 LRSs on pathways #23-#37
(e) additional 4 LRSs on pathways #25, #30, #32 and #34 in scenario (c)

Fig. 4. Estimated Density by UPF [3] and Detection Ratio of People

IV. EXPERIMENTS

In order to validate usefulness of HumanS, we have simulated a monitoring-based crowd and flow estimation system called UPF [3] with modeling of underground city of Osaka [1] that has a huge number of visitors (A total of 600 thousand people/day). We have focused on a $300m \times 300m$ square region in the distinct and set 22 origin/destination points, which were selected from the entrances of office/commercial buildings and stations as well as stairs from/to the ground level. The generation rates of human agents have been decided based on the real population data of surrounding office buildings and stations [2] to create a realistic flow of pedestrians. The generated people density was totally inhomogeneous (1,200 people were in the region at each moment and the average density was 0.12 persons/m^2), and most of them followed the shortest paths between those points since they are office workers and commuters.

UPF assumes monitoring people density at multiple points to estimate pedestrians' entire flows. For this monitoring purpose, we have used the laser range scanner (LRS) model with 10m maximum range, 60 degrees of angle (with 3 degree angle resolution) and 2 second scan interval. Since the LRS model cannot detect objects behind others, there are always miscounting of people. To observe the impact of such a sensor-dependent property on the performance of the target sensing system is one of our objectives.

We have prepared the following five scenarios to see the impact of sensor capability, sensor location, and the number of sensors. We note that there were 37 pathways generated on the given map, and Fig 3 shows the true density (ground truth) in the generated mobility. A screenshot has been shown in Fig. 1.

(a) 37 "perfect" sensors on all pathways (every pathway has a sensor, which can perfectly count the number of people that reside in the sensing region without errors)
(b) 37 LRSs on all pathways (every pathway has a LRS)
(c) 22 LRSs on pathways that are connected to entrances (only pathways that are close to origin/destinations are monitored by LRSs)
(d) 15 LRSs on pathways that are NOT connected to entrances (only pathways that are far from origin/destinations are monitored by LRSs)
(e) additional 4 LRSs in scenario (c) (location was manually chosen)

Fig. 4 shows the estimated densities (bars along the left Y-axis) on pathways as well as detection successful ratios of people using the perfect or LRS model ($\times$ plots along the right Y-axis). Scenario (a) has achieved the best accuracy of estimated density (ave. error of density was 0.013 persons/m^2 (10%), while that of scenario (b) was 0.017 persons/m^2 (17%). It is clear that this 7% difference is due to difference of sensor capability, which is significant in sensing systems. Actually only 11031 out of 14013 people were detected by LRS in scenario (b) (*i.e.* detection ratio=79%). To convince readers of this fact, we have also measured in the same experiment the correlation between density and detection ratio by the LRS model in Table. I, which shows a clear decreasing trend as the increase of density. We note that even with the perfect sensors on every pathway, the estimation is not perfectly identical with the truth due to the capability of UPF.

In scenario (c), we can see large errors on pathways without LRSs, but the average error was 0.027 persons/m^2 (28%). On the other hand, that of scenario (d) was 0.083 persons/m^2 (132%) although more people could be detected than scenario (c). This exactly shows the requirement of UPF for better performance. UPF needs observation of density at different points, which are away from each other for more global capturing of their moving paths.

Finally, according to the simulation result of (c), we have tried to improve the accuracy by manually adding limited number of LRSs in (e). As a result of adding only 4 LRSs, we could substantially improve the accuracy; the error became $0.014/m^2$ (14%), which is very close to the performance in scenario (b). This is a surprising finding and contributes to more cost-efficient monitoring of pedestrians activity.

These experiments clearly show that HumanS can evaluate such a human sensing systems like UPF with different settings of sensors (and mobility patterns as well).

V. Conclusion

We have designed and developed a human sensing system simulator called HumanS. HumanS simulates walking behavior of people in city sections and most importantly it can simulate the behavior of sensors that capture those people in the simulator. All the data can be comprehensively managed by GIS databases for the development of such human sensing based applications. We have shown the usefulness by a case study of sensing human behavior in the Osaka underground where mobility was simulated based on real statistical population data. More detailed information can be found at http://www-higashi.ist.osaka-u.ac.jp/research/humans/.

We are also planning to extend HumanS to allow thermo-fluid analysis. In addition to object detection sensors, we will develop air sensor models to measure temperature, humidity and CO_2 which are important parameters for air flow control in building and underground.

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