Map Data Representation for Indoor Navigation

A design framework towards a construction of indoor map

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***Abstract*—A map is a basic component used in a part of navigation in everyday life, which helps people to find information regarding locations, landmarks, and routes. By GPS and online service map e.g. Google maps, navigating outdoors is easier. Inside buildings, however, navigating would not be so easy due to natural characteristics and limitations of GPS, which has led to the creations of indoor navigation system. Even though the indoor navigation systems have been developed for long time, there are still some limitation in accuracy, reliability and indoor spatial information. Navigating inside without indoor spatial information would be a challenge for the users. Regarding the indoor spatial information, a research question has been drawn on finding an appropriate framework towards map data representation of an indoor public spaces and buildings in order to promote indoor navigation for people, robotics, and autonomous systems. This paper has purposed a list of factors and components used towards the design framework for map data representation of indoor public spaces and buildings. The framework, in this paper, has been presented as a form of a multiple-layered model, which each layer designed for a different propose, with object and information classifications.**

***Keywords*—framework; data representation; indoor map; indoor navigation; classification; accessibility**

I. Introduction

Navigation outside these days is easier than the past since some technologies have been invented such as a global positioning system (GPS) and public service map like Google, which are both working together to navigate people to the destination. A map is apparently a basic component used in a part of navigation everyday life for everybody which is helping people find information regarding location, landmark and route planning. However, navigating inside the building would not be easy as it does so well outside the buildings. Due to natural characteristics and limitations of GPS, it provides an inaccurate position estimation. This leads to the creation of indoor navigation system (IPS). Even though it has been so-long invited, there are still some limitations in accuracy, reliability and also indoor spatial information. Indoor spatial information, especially, has come into play as a main role in the navigation process. There is a small number of research and commercial products regarding indoor spatial information discussed in the literature. Furthermore, an observation has said that for 80-90% people have spent their daily life inside the building [1]. As a matter of fact, indoor spatial information is the most important in terms of promoting indoor navigation. Besides, indoor spatial information could be of use towards indoor-based application such as indoor navigation system, security and surveillance systems, and context awareness computing system, robotics, and even autonomous systems in industries, e.g. self-driven vehicles, self-picking robotic and item-finder for Amazon's warehouse [2]. Explicitly, this information also benefits everybody e.g. visually impaired and blind people, who are seeking tools providing information while navigating inside public spaces and buildings (hospitals, airports, universities, department stores).

To promote indoor navigation, it will be best to understand what essential information to be included in a map data representation in order to cover all of problems and challenges. For this reason, it leads to our research questions on finding what essential information need to be integrated into the map data representation in order to promote indoor navigation, and what an appropriate framework for the construction of indoor map.

Section II will describe related works regarding indoor navigation systems, maps and data representation for indoor spatial information. Afterwards, in Section III, a framework will be discussed with objects and information classification are included. Section IV presents an overview of the framework with its potential application and extensions.

II. Related Work

To understand how best to design the framework of map data presentation of indoor public spaces and buildings in order to promote indoor navigation, our framework is importantly informed and developed by prior a numerous research and study in designing indoor navigation and the indoor map.

A. Indoor Positioning and Navigation System

Even though GPS is the most powerful tool widely used for navigation these days, its performance is weak when deployed inside buildings due to its characteristics and limitations. To fill the gap, researchers have studied indoor navigation system in various techniques such as RFID [3], Radio Map (Bluetooth [4], Wi-Fi [5], commercial products: Indoo.rs and Wifarer), Ultra-Wideband [6]), Ultrasound [7], Inertia Sensor [8], Optical ([9], OrCam) and Visible Light

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[10]. Many reasons have led into this subject since many applications could take this advantage of IPS e.g. indoor navigation systems, robotics, and autonomous systems. By cooperating with an indoor map, IPS is equipped with indoor spatial information which is providing features into the system. For example, route planning, navigation. An indoor map given into the system, on the contrary, is usually plain, raster image. Some commercial products provide a vector graphic into the system, but still lacks of information and not well-informed which demotes indoor navigation capability.

B. Maps and Data Representation

An important component used in navigation these days is a map which provides people information regarding locations, destinations, and routes, which all are usually provided only outdoors. Inside buildings, on the other hand, would be another story due to the difficulties of providing information and detail of the buildings which are important to the indoor navigation [3]. Several studies and commercial products of indoor-based localization and navigation are mostly developed as standalone systems and usually place the indoor maps of certain areas in form of raster or vector graphics on top of Google Maps [11]. Regarding the indoor map, Google has also proposed a brand new indoor map platform, called Google Indoor Map, a crowd-sourcing model providing a feature that allows user to create 2D indoor map with a basic indoor information placed on top of Google Maps which is suitable for general purposes. However, those features would not be enough for complicated tasks such as a self-driven car at the airport or autonomous self-picking or item-finding at a warehouse that requires further information to promote indoor navigation capability such as the presence of objects, obstacles, transitions, and accessibility information.

Towards a construction of indoor maps, in [12], the authors proposed basic components used in the construction of indoor spatial information in a three-dimensional geography, called IndoorGML, designed for robotics navigation, influenced by CityGML, a standard markup language for a city in a three-dimensional geography [13][14]. With such a huge benefit brought by IndoorGML, this propose has become a standard markup language for indoor spatial representation [15] whose data models are designed in forms of open data. In this study, the authors have proposed two modules, (1) core module and (2) indoor navigation module. The core module is designed as a multiple layered model representing indoor spaces, which consists of two layers: topographic and sensor. The first, the topographic layer, contains information regarding floor layouts of the building and the relationships between spaces, rooms, dimensions, and physical features and appearance, which consists of spaces (state) and transitions (connectivity). The second is a sensor layer that contains information about sensors installed in the buildings such as access points (Wi-Fi), RFID, cameras, visible light communication and other sensors where information of each sensor is separately stored in a different layer. The indoor navigation module presents a set of nodes connected to each other via edges overlapping on top of topographic layers in order to indicate a connectivity between room and navigable spaces, and also indicate if route is whether restricted.

III. Framework for Map Data Representation

To promote indoor navigation capability, as a matter of fact, two major components need to be taken into account as they provide complementary information given into the system. The first component is objects, which can be furniture, obstacles or barriers disabling the ability to navigate inside a building. The second component is information about the buildings, which could be anything e.g. general information, floor plans, way-finding, exhibitions, events, and external information.

Considering the gap of technologies and their limitations, a framework of map data representation has been proposed. In this section, the framework is designed by considering the gap of technologies, problems and challenges found in the literature. In a design framework, shown in Fig. 1, the framework is split into seven layers, extending the three layers of IndoorGML [15] by including three layers of object classification and one layer of information.

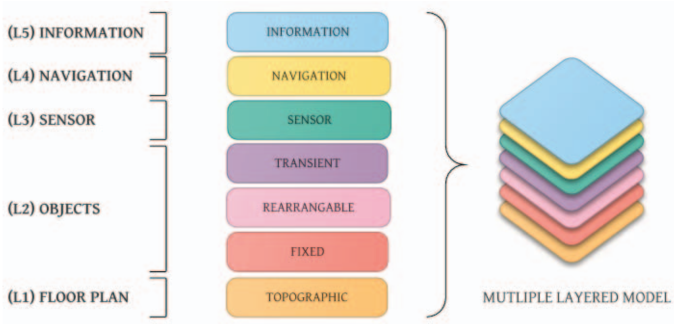

Figure 1. A conceptual framework for map data representation adapted from IndoorGML [15]

To fulfill the gap of IndoorGML, a conceptual framework has been proposed for autonomous systems (e.g. self-driving vehicle and robotic) to have an ability to detect surrounded environments which could be of use in the airports, hospitals, warehouses which is offering transportation facilities to people with disabilities, who are not comfortable to walk in a long distance. Furthermore, this would be used to greatly improve the process of shelf-picking or item-finding in the warehouses, e.g. Amazon's warehouse [2]. To solve these problems, a multi layered model approach has been designed and split into seven layers accordingly. For the definitions of each layers are listed below:

Topographic, the bottommost layer accounts for a floor plan showing the relationships between rooms, spaces and entrances for all of the floors of the buildings in a three-dimensional geography including physical dimensions, size, and type of wall. This consists of two sub-layers, space (state) and connectivity (transition) which determine how rooms are connected with each other via transition links. This layer is compulsory as a main component of the indoor map. Given a topographic, the floor plan is formed as a general indoor map inside the buildings without an internal information, also known as interior design information.

Fixed Objects, this layer contains information about objects that are fixed, installed, attached to the buildings as defined for furniture, doors, stairs, lift or some objects that are permanently installed. Also, providing some barriers like drop- offs, curbs, and also construction areas or building renovations which will take a long time to complete. This layer is, therefore, responsible for many challenges like giving a free mobility, warning information for critical areas, landmarks, so on. To classify objects, a scaling method will be discussed in Section III-B.

Rearrangeable Objects, this layer contains information about objects that can be rearrangeable by force from someone. This layer is designed for some objects like table, chairs, and other lasting in their position for a medium to a long period depending on a movability factor. This layer is responsible for random objects in terms of obstacle detection and avoidance. To classify the objects, a scaling method will be discussed in Section III-B.

Transient Objects, this layer contains information about objects that last for a short period like people, weather changes. This layer will be used in case of measuring indoor traffic, detecting people, calculating an appropriate route for the autonomous system and people. To classify the objects, a scaling method will be discussed in Section III-B.

Sensor, this layer contains information about sensors, one layer contains only one type sensor, allowing sensors placed on the indoor map, such as a camera, RFID, Wi-Fi, smoke detector, lighting, door switch sensor, or others. As a result, this layer is mostly responsible for many applications and extensions such as indoor localization and navigation, obstacle detection, security and surveillance, and others.

Navigation, an important layer representing navigable paths on the indoor map enabling people to know which path can be walked on. This layer can be used in part of route planning and, in particular acting as calibration points for the indoor positioning system.

Information, this layer provides essential and useful information regarding indoor navigation, e.g. context and spatial awareness, provided to people and autonomous systems. This layer will be of use to provide information regarding navigation to support way-finding when individuals and autonomous systems are navigating inside unfamiliar buildings. This includes, for example, a room number and name, a description of the exhibitions in a museum and healthcare information in a hospital. In this layer, information will be classified, as discussed in Section III-C.

A. Reference Model

Given the diagram (Fig. 1) and definitions, this framework is arranged in a reference model in terms of a design implication that indoor spatial information is represented by a collection of data and relationships mapping between layers in a reference model, shown in Fig. 2. It is so obvious that the most important component of the map is layout and spaces connectivity. Thus, it is inevitable to make the topographic layer as the bottommost (level 1) layer while information is arranged at the topmost (level 5) layer since it acts as complimentary information for people and autonomous systems. Object classification layer is placed at the second (level 2) layer representing the information of the objects installed inside the building, and so is the sensors layer (level 3) which is originally designed for the indoor positioning system by IndoorGML. In the framework, this layer is extended to have more types of sensor (e.g. security camera, light, magneto, ultrasound, IR, smoke and heat detector, etc.) whose information can be utilized for various purposes such as security and surveillance, lighting, network planning, and especially indoor navigation system which cooperates with the navigation layer (level 4) that provide a navigable route inside the buildings.

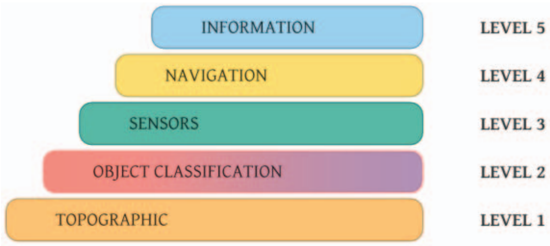

Figure 2. Reference Model for the design framework of indoor map representation

Table I describes an example of how each layer comes into play with the other layers to support the future developments. In L1, the bottommost layer is responsible for the construction of the floor plan of all floors in the building, which is a general indoor map. With object classification (L2), the floor plan is equipped interior information which is used and responsible for indoor spatial awareness. In the sensor layer (L3), equipped with the sensors' information, the applications can be extended, for example, Camera: object detection and avoidance, and security and surveillance, Wi-Fi: indoor positioning system, network planning, map insight, and RFID: indoor navigation and access control. In L4, the navigation layer, navigable paths are provided to people, robotics and autonomous systems to know which area are navigable. This layer is also designed and used in the indoor navigation system. In the topmost layer (L5), information layer provides complimentary information to people, especially ones who is visually impaired and blind who need further information to help them to have an independent navigation inside the buildings. This information can also be applied into robotics and autonomous system as well. This layer is potentially designed to provide a free mobility information to people with disabilities to learn what they are

TABLE I. BOTTOM UP DESIGN OF THE FRAMEWORK AND ITS POTENTIAL APPLICATIONS

Level	Description	Applications
L5 – Information	Building's profile, way-finding, exhibition, event, external information	Indoor Navigation for People with Disabilities, Accessible Map (interactive), Context Awareness
L4 – Navigation	Navigable paths	Indoor Navigation for Autonomous System and Robotic, Indoor Route Planning
L3 – Sensor	Camera, Wi-Fi, RFID, others	Indoor Positioning System, Network Planning, Security and Surveillance, Map Insight, Obstacle Detection and Avoidance, Access Control
L2 – Object Classification	A fixed, rearrangeable, transient object	Floor Plan with Interior, Spatial awareness Accessible Map (standard)
L1 - Topographic	Relationships of rooms, spaces, entrances	Floor Plan (a general indoor map)

going to experience, and context awareness computing system.

B. Object Classification

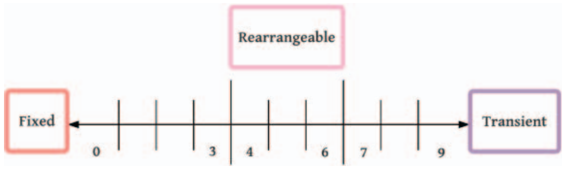

Figure 3. Scale based object classification

In these layers, object is classified into sub-categories such as fixed, rearrangeable, and transient objects which are separately used in different purposes for promoting navigation indoors. In particular buildings like hospitals, department stores, airports, objects like elevators, escalators, and travellators are fixed installed inside the buildings, and also have a transportation (moving) ability in order to move something from state or another state. This term could be confusing since moving objects like people are also considered as moving (transient) objects. To minimizing the confusion, terms of object and transportation object will be declared as follows:

1) Object is a representation of a physical object that can be everything that has a surface and touchable. The objects can be split into three types of object by considering a movability factor such as a fixed, rearrangeable, or transient object

2) Transportation objects are fixed objects that provide the capacity to transfer objects from one state to another state. For example, escalator, a moving staircase, is a transportation device driven by an electric motor for carrying people from one floor to another floor, and so are elevator or travellator.

3) Self-Moving objects are transient objects that has self-moving abilities, e.g. people, pet, and autonomous systems.

From Fig. 3, a scale based classification method have been used in terms of object classification. The object is classified into one of the three categories by considering a movability of the objects (objm), shown in Table II which definitions of each type are defined.

1. Fixed Object, a predictable object is permanently installed or attached inside the building in any height (ground, body, or head level) such as floor-mounted types of furniture, wall- mounted types of furniture, stairs, elevators, escalators, travellator, and stair.
2. *Rearrangeable Object,* an unpredictable object is placed in the building and rearrangeable by someone like a table, chair, refrigerator, freezer, computer, workstation, and office plant.
3. Transient Object, an unpredictable object always moves inside the building, such as people, crowd, weather changes (sensory information e.g. sunlight and rain), and autonomous systems and robotics.

C. Information Classification

In this layer, information will be classified into six of subcategory, shown in Fig. 4. By integrating this layer into the framework for map data representation, this layer acts as a meta data that enables people and autonomous systems to have infor-mation about surrounded environment inside the buildings.

Basic, general information about the building which is provided to users such as building profile, type (organization, university, hospital, and museum), pre-visit information, open hours, front desk information, and FAQ.

Floor plan, information describes the details the buildings regarding a floor plan such as rooms (number, name, and type) and areas (hallway, living, and kitchen). For example, "4036, Jo Axtell, Office, 10.00-17.00".

TABLE II. OBJECT CLASSIFICATION: SCALING DEFINITION AND EXAMPLES

Type	Scale	Definition	Example
Fixed Objects	0	Permanently come with the building, cannot be changed	Stair, Sidewalk, Pavement/ Drop-off, Sloped floor, Curb/ Hole on the ground
	1	Installed in the building, impossible or hard to uninstall	Elevator, Escalator, Travellator/ Fence
	2	Installed in the building, can be removable.	Floor-mount furniture/ Wall-mount furniture Built-in furniture/ Bathroom stuffs (basin, shower bowl, toilet)
	3	Temporary installed in the building with time period.	Construction area/ Building renovation
Rearrangeable Objects	4	Large object that is difficult to reposition due to a physical appearance.	Refrigerator, freezer (Family size)
	5	Medium object that is sometime difficult to reposition.	Table, Chair/ Small refrigerator, Freezer Personal Computer, Workstation/ Office plant
	6	Small object that is easy to reposition or detachable	Litter-bin/ Rug/ Portable Equipment Fire extinguisher
Transient Objects	7	Unintentional or accidental object	Wet floor Litter
	8	Objects created by schedules	Cleaning area
	9	Self-moving objects	People, Pet/ Robotic, Autonomous System

Wayfinding, essential information is used to promote indoor navigation such as pavement information, transition space information (e.g. stairs: steps, width, height, where is

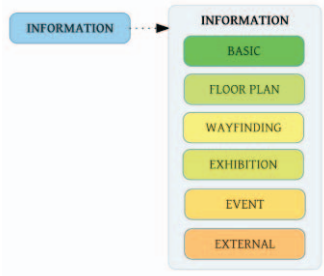

Figure 4. Sub-categories for the information classification

handrail), Transition spaces' status (e.g. door is opened/ closed? Elevator is 4th floor, Escalator/Travellator is active/ inactive?), sign, intersection, and corner markers.

Exhibition, information describes details of the objects which are placed in the buildings provided by museums, hospitals, offices or universities in various types of media such as posters, announcements, and leaflets. For example, Museum: Object A, "Mona Lisa", "a portrait of a woman by Leonardo da Vinci".

Event, information describes events which are held in the buildings that enables people to be informed such as What is the event about? Where is the event held in the building, and the event layout? Which companies participate in the event including information about the companies, products, and promotion that are potentially impacting to the business aspect.

External, information describe the environment happen in the area which impacts people with disabilities e.g. visually impaired and blind people travelling inside the buildings, such as light goes through windows, noise from constructions outside the buildings. However, this information will be provided by third-party services (BBC Weather, The Weather Channel, or Yahoo Weather Forecasts) or sensors (noise measurement sensor and camera).

IV. Applications and Extentions

To increase the indoor spatial awareness, the framework has been designed in a form of the multiple layered model, shown in Section II, with different scenarios taken into account. This section describes how the framework comes into play in various scenarios in order to cover the problems and challenges, how information is stored in the map data representation. Compiling all layers together, the buildings are logically visualized in a 3D, providing all of the information that will be of use towards indoor navigation and indoor-based applications. Fig. 5 presents the potential applications and extensions for the future developments. For instance, accessible map, indoor navigation for disabled people, context awareness, security and surveillan-ce, and insight. This approach could also be applied to robotics and autonomous systems in various buildings such as airports, museums, hospitals, universities, or other buildings. Table III illustrates examples of information will be stored in different scenarios and potential applications and extensions included.

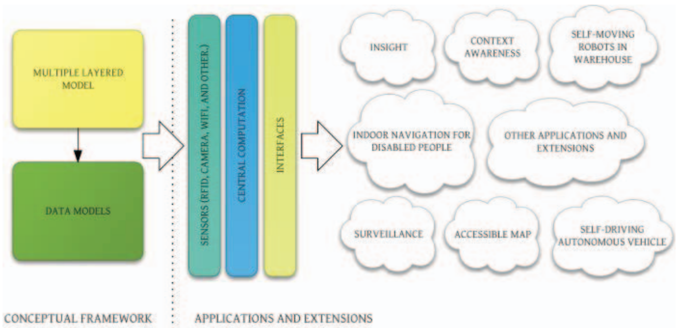

Figure 5. Applications and extensions might have potentially adopted the use of framework

Layers		General Building	Airport	Department Store	Hospital	Museum
Topographic		Information of buildings such as floor layout, room topographic, dimension				
Object Classification	Fixed	Stairs, Elevator	Stair, Elevator, Escalator, Travellator Mounted furniture and equipment	Stairs, Elevator Escalator	Stairs, Elevator, Escalator Medical Equipment (large)	Stair, Elevator Display cases
	Rearrangeable	Table, Chair, Computer Office furniture and plants	Table, Chair Wall-mount equipment Flights boards	Table, Chair Wall-mount equipment	Table, Chair Medical Equipment (small/ medium, movable)	Long chair
	Transient	People	People Electric Vehicle Baggage Carts	People Guide dog	People, Wheelchair, Hospital Beds	People
Sensors		Wi-Fi information, RFID information (for access control), Camera (for security and surveillance)				
Navigation		A set of navigable paths that allow people walk through that will be used in route planning and indoor navigation				
Information	Basic	Building Profile and Information	Flight Timetable Transport Information Airport Guide and Directory	Department Store Information and Directory Visitor Information	Hospital Information and Profile Front Desk Information,	Museum Profile and Information
	Floor Plan	Room number and name Open hours	Area name	Store location and name Open hours	Room number and name Area name	Area name
	Wayfinding	Information is used for promoting blind navigation and wayfinding such as Stairs: steps, width, height, where is a handrail, Door is opened/closed? Elevator is the 4th floor, Escalator/travellator is active/inactive?, Signage information, and Intersection and corner markers.				
	Exhibition	Information describe objects placed in the buildings provided by museums, hospitals, offices or universities in various type of media				History and tradition information of exhibitions and collections
	Event	Information describes the events: What is the event about? Where is the event held in the building and its layout? Which companies participate in this event including their information of the companies? Note that information of products and promotion are potentially impacting to business aspect.				
	External	External information that impacts visually impaired and blind people travelling inside the buildings, such as light goes through windows, noise raining, construct outside the buildings, or even car horn when the traffic is jamming.				
Application and Extensions		Indoor Navigation Accessible Map Security and Surveillance	Indoor Navigation Accessible Map Security and Surveillance Autonomous System	Indoor Navigation Accessible Map Context Awareness Map Insight	Indoor Navigation Accessible Map Spatial Awareness	Indoor Navigation Context Awareness

V. CONCLUSION

Considering problems and challenges found in the literature and commercial products, many limitations has been disclosed about indoor navigation system, map and data representation. A map, however, is the one of the basic component used in every indoor navigation system, as the map provides indoor spatial information to the indoor navigation system. To solve the problems and challenges, the framework has been designed and discussed in a form of the multiple layered model. To promote indoor navigation capability, three layers objects classification and six sub-categories of information classifications were introduced. Finally, the potential applications and extensions of the framework were presented in terms of future developments, including the example of information stored in different layers in different scenarios are included.

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