Automatic Floorplan Generation of Living Space for Simulating a Life of an Elderly Resident Supported by a Mobile Robot

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Abstract –

A mobile robot follows a resident and grabs his/her health condition using a Kinect sensor. The 3D environment of the robot's working space has a huge impact on the design and operation of the mobile robot in two aspects: (1) it defines movements of the resident; (2) it affects the view and trajectories of the robot. This paper proposes an efficient and lightweight floorplan generator which automatically samples 2D semantic floorplans. With the height function, generated floorplans can be converted to diverse 3D indoor scenes. Secondly, based on a floorplan, movements of the resident during a period can be generated automatically with his/her activity schedule. Generated 3D scenes with resident movements will be used to evaluate how indoor spaces affect the design and operation policies of the mobile watching robot. The diversity of scenes with movements has two benefits: (1) providing massive data to constitute a training set for machine learning algorithms; (2) various scenes can be classified for finding statistical conclusions.

Keywords –

Floorplan; Automatic simulation; Mobile robot; Elderly people living alone; Design; Operation policy

1 Introduction

The elderly population around the world is steadily increasing. The estimated number of people aged 65 years and older was 524 million in 2010 and is forecasted to increase to 1.5 billion by 2050. [1] Most elderly people preferred to live with family members, but the proportion of them choosing to live alone has shown an increase in recent years. [2] For elderly people, living alone is associated with elevated mortality, a study undertaken it shortened survival by 0.6 years. [3] Although elderly people living alone would benefit from nursed by specialized agents, the shortage of global aged care workforce makes this difficult.

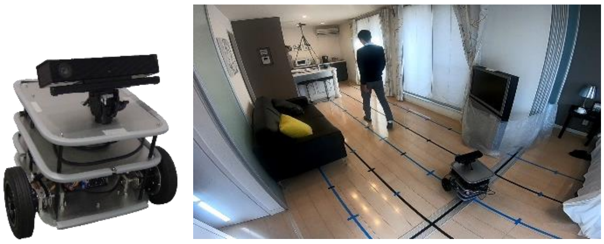
However, recent improvements in robotic, AI and IoT technologies provide some options to address this challenge. For example, monitoring systems were integrated into smart houses. Generally, there are two schemes to grip the health condition of elderly people by using: (1) wearable sensors, such as wearable inertial sensors [4]; (2) stationary sensors, such as cameras [5], passive infrared (PIR) sensors [6, 7], pressure-based item sensors and magnetic door sensors [7]. Secondly, mobile robots were used to support the independent elderly. These robots mainly observed the state of resident, their functions included fall detection [8] and human activity recognition (HAR) [9, 10], and they had additional functions such as interaction, object grasping, entertainment and floor-clean [8].

We focus on using a mobile robot, e-bio (Figure 1a), to monitor the health condition of elderly independent residents with a Kinect V2 sensor. Figure 1b shows the robot tracking people and observing his walking pattern in a studio apartment. Our robot focuses on resident monitoring and omits the functions like interaction and grasping, which reduces its size and degree of freedom. The advantage is that our robot is more economical and affordable for consumers, but the lower and fixed watching view of the Kinect sensor is more vulnerable to indoor obstacles such as furniture when the robot is tracking people and planning its trajectories.

Therefore, some issues regarding our robot need to be addressed, such as:

- Will the robot work well when monitoring an elderly resident?
- How should we adjust the height of the robot and the fixed angle of the Kinect sensor in different indoor scenes to balance its tracking performance and manufacturing cost?
- What operation policies should the robot use for its purpose?

We plan to address these issues by simulation, so indoor environments and elder people’s movements and activities should be simulated as preconditions. Instead of researching few cases, our aim is to obtain statistical results from diverse indoor scenes, the finalized framework of this study is shown in Figure 2.



a) b)

Figure 1. Our robot and its utilization: (a) e-bio, (b) e-bio tracks people

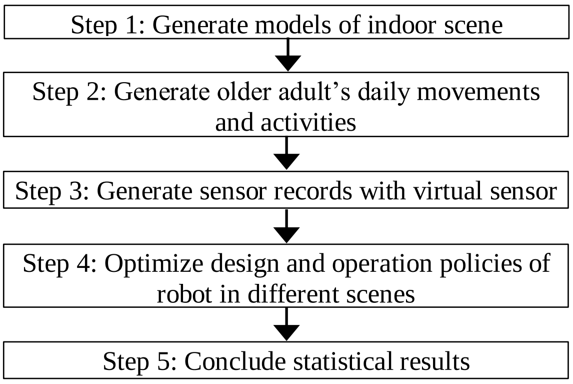


Figure 2. Framework for general study

This paper proposes a generator to automatically produce diverse floorplans for studio apartments, which addresses the primary challenge of Step 1 of the framework. Section 3 describes the basic rules and methodology to generate floorplan; Section 4 details the performance of the generator; Section 5 describes how to convert a floorplan to 3D scene and how to generate resident’s paths based on the floorplan.

2 Related Works

2.1 Simulation of Smart House

In recent years, many smart house simulators were proposed because building real smart house test beds was expensive and time consuming. These simulators generated testing data for different purposes such as optimizing the arrangement of house components and sensors [11], human activity recognition [12], ubiquitous application testing [13] and location-based service testing [14].

These simulators enabled smart house designers to verify their ideas and plans. However, they had two shortages: (1) models of house were built manually, (2) virtual residents repeated a predefined schedule or were controlled by users.

To handle the second shortage, Lee et al. [15] proposed a smart house simulator with an automatic virtual resident. This simulator used a motivation-driven behavior planning method to force the resident to interact with the house. During simulation, resident’s motivations such as hunger, thirst, and the need to study were generated. However, users still need to build the house model. Furthermore, this simulator did not meet our demands because the virtual resident did not imitate the elderly. The actions and movements of the elderly are slower than the average level and some of them may fall down or suffer from dementia. We should consider these situations in our simulation.

2.2 Floorplan Generation

Floorplan is a 2D semantic map which shows the relationships between physical features of the architecture such as rooms, doors and furniture. Automatic floorplan generation is necessary for our research.

There are two main steps to generate a complete floorplan: (1) deciding the relationships between rooms, (2) placing furniture inside the rooms.

In aspect of the first step, Hahn et al. [16] focused on the interior generation of a large building. They divided the floor into room clusters with parallel hallways. However, the room clusters were regular rectangles and most rooms were the same size. Mirahmadi et al. [17] divided a rectangle house into rooms using Squarified Treemap algorithm. They decided the areas of each room and sorted the areas in descending order, which was the input for the algorithm. This generator is unstable because of the limitation of the algorithm, the areas must be decided carefully. Ma et al [18] generated floorplans based on topological relationship between rooms. They input a topological map and all room blocks, then combined the blocks based on the map. But this generator can not avoid gaps between blocks.

In aspect of the second step, Anderson et al [19] automated desk layouts for diverse offices. Tutenel et al [20] proposed a layout solver which places furniture according to rules defined by users. Users could set rules such as “place X instances of class Y” and “place as many objects of class Z as possible”. Henderson et al [21] proposed a data-driven, probabilistic, generative model for room layouts. This model learned statistics from 250, 000 room models designed by human.

For future studies, we hope to develop an efficient and lightweight floorplan generator for residences; the generators mentioned before do not meet all our demands.

3 Floorplan Generation

Our laboratory's robot has been tested in a studio apartment shown in Figure 3. [22] Different from most dwellings, studio apartments have a large main room where the elderly can sleep, cook and watch TV.

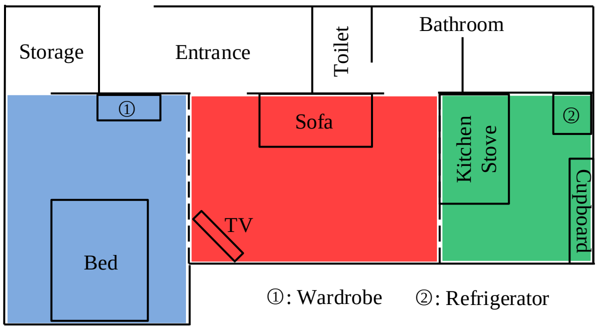


Figure 3. Studio apartment in the test

In Figure 3, the studio apartment includes a main room, entrance, toilet, bathroom and storage. The main room was the working space of our robot, we divide the room into three zones according to the furniture inside them: resting zone (blue area), living zone (red area) and cooking zone (green area). There are no physical boundaries between zones, resident passes through the virtual boundary (black dashed lines) to enter another zone. The walls of the house are represent by black solid lines, and gaps represent doors.

When placing furniture in the main room, normal procedure is: (1) deciding shape and size of the room, (2) dividing room into zones, (3) placing furniture into each zone. But a reverse thinking, deciding size of all zones first and then combining them into the room, has two advantages: (1) The room's shape is usually not a regular rectangle, but the shapes of zones always are; (2) In the future, we will research the dwelling owning separate bedroom, livingroom and kitchen, the reverse method will be more extensive.

3.1 Generation Rules

The desired floorplan describes 2D semantic information of additional rooms, zones, furniture, doors and walls. Additional rooms include a toilet and bathroom, Zones are the working space of virtual robot, which include the resting zone, living zone and cooking zone. There are three classes of furniture:

- Resting furniture includes bed, wardrobe, writing desk-chair set and nightstands.
- Living furniture includes dining table set and sofa-TV set. The dining table pairs one to four chairs.
- Cooking furniture includes kitchen stove, cupboard, refrigerator, wash machine and trash bin.

Each furniture is only inside its corresponding zone. Doors include the entrance, toilet door and bathroom door. The entrance connects zones with external areas (other rooms not in the model or outside of the house). Walls are the boundaries of additional rooms and the union of zones (no walls in the boundaries between zones).

The rules in Section 3.1.1 and 3.1.2 define the size of each element and topological relationship between them.

3.1.1 Rules about Size

In reference to the London Housing Design Guide [23], seven rules are proposed to balance realism and efficiency of our generator.

SR 1. The sizes of the toilet and the bathroom are 0.6 × 1.2m and 1.8 × 1.2m. The 1.2m-long sides are wing sides. The remaining sides are face side and rear side, respectively.

SR 2. The lengths of all sides of all zones are multiplies of 0.2m.

SR 3. The aspect ratios of all zones are less than 2.

SR 4. The area of the resting zone, A_R, is in ($8m^2$, $16m^2$). The area of the living zone is in ($12m^2$, $24m^2$) and ($1.2A_R$, $1.8A_R$). The area of the cooking zone is in ($6m^2$, $12m^2$) and ($0.6A_R$, $0.9A_R$).

SR 5. The furniture size candidates are listed in Table 1.

SR 6. When sampling the size of a furniture item, the area of the zone impacts the generator. Appearance of large furniture in large zones occur with a higher possibility.

SR 7. The lengths of doors are 0.6m.

3.1.2 Rules about Topology

There are seven rules about the topology of generated floorplans:

TR 1. The toilet must connect with the bathroom along one of its wing sides (SR 1). The same with the bathroom.

TR 2. The toilet can connect with the living zone and the cooking zone, the bathroom can connect with the living zone and the resting zone. They connect with zones along their rear sides (SR 1).

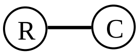
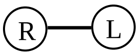
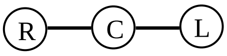
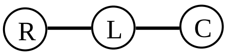
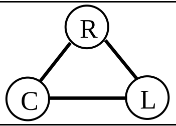
TR 3. The toilet and bathroom may be inside or outside of the zones to which they are connected.

TR 4. The generated floorplan must include the resting zone, may include either the living zone or cooking zone or both. The topology candidates of zones are

Table 1. Furniture size candidates

Furniture	Candidate sizes (m)	Furniture	Candidate sizes (m)
Bed	2.1 × 0.9, 2.1 × 1.2, 2.1 ×1.5, 2.1 × 1.8	Writing desk-chair set	1.0 × 1.0, 1.2 × 1.0
Wardrobe	0.6 × 0.6, 0.8 × 0.6, 1.0× 0.6, 1.2× 0.6	Nightstand	0.4 × 0.4
Dining table	0.8 × 0.8, 1.0 × 0.8, 1.2× 0.8, 1.4× 0.8, 1.6 × 0.8	Writing desk	1.0 × 0.5, 1.2 × 0.5
Sofa-TV set	3.0 × 0.9, 3.0 × 1.4, 3.0 × 1.9	Chair	0.4 × 0.4
Kitchen stove	0.6 × 0.6, 1.2 × 0.6, 1.8 × 0.6	Refrigerator	0.6 × 0.6
Cupboard	1.0 × 0.5, 1.2 × 0.5, 1.5 × 0.5	Wash machine	0.6 × 0.6
Sofa	0.9 × 0.8, 1.4 × 0.8, 1.9 × 0.8	Trash bin	0.6 × 0.3
Furniture	Candidate sizes (m)		
TV table with TV	0.6 × 0.4, 0.8 × 0.4, 0.8 × 0.6, 1.0 × 0.4, 1.0 × 0.6, 1.2 × 0.4, 1.2 × 0.6		

Table 2. Topology candidates of zones

Type	1	2	3	4	5
Topology					

listed in Table 2, where ®, Ⓛ and © represent the resting zone, the living zone and the cooking zone, respectively.

TR.5 There are two relationships between a furniture and walls, against a wall or not. A writing desk-chair set and dining table set are not against a wall, all others are against a wall.

TR 6. A furniture item is at least 0.6m away from any other furniture items and doors.

TR 7. The entrance can appear in any wall except in the toilet's and bathroom's walls. The toilet door and bathroom door appear in the middle of the face wall (SR 1) of the corresponding room.

3.2 Methodology

A sample floorplan is generated in three steps: (1) placing zones and additional rooms, (2) generating walls and doors, (3) placing furniture inside each zone.

3.2.1 Placing Zones and Additional Rooms

As the resting zone must be included (*TR 3*), we first sample its size based on *SR 2* to *4* and set the center of the zone to the origin of the coordinate system. We then sample a topology from Table 2 and combine zones and additional rooms based on sampled topology and *TR 1* and *2*. The toilet's and bathroom's size are defined by *SR 1*. To achieve realism and avoid gaps in the floorplan, we should align connected zones and additional rooms.

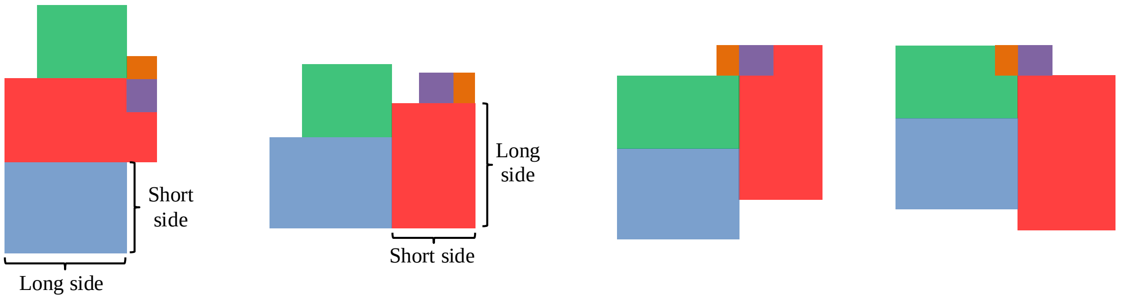
Figure 4 shows the principles of the alignment. In Figure 4a, when a zone parallels the resting zone (topology 1-4 in Table 2), it must at least be aligned with a short side of the resting zone, and its connected side must be equal to or 1.2m shorter or longer than the long side of the resting zone (1.2m is the length of toilet and bathroom wing sides). Figure 4b, 4c and 4d show that when the living zone is perpendicular to the resting and cooking zones (topology 5 in Table 2), it must connect with the aligned sides of these two zones along its long side. One of its short sides must be aligned with an edge of the union of the resting and cooking zones or exceed or fall short of the 1.2m edge.

3.2.2 Generating Walls and Doors

After placing the toilet and bathroom, it is easy to generate the toilet and bathroom doors with *TR 7*, and the walls are also easy to define. We then sample a wall to place the entrance. The entrance appearing in a wall shorter than 2.0 m or longer than 4.0 m occurs with a higher possibility due to *TR 6* (most furniture items are against a wall). The entrance should be placed close to one end of the wall rather than in the middle for the same reason.

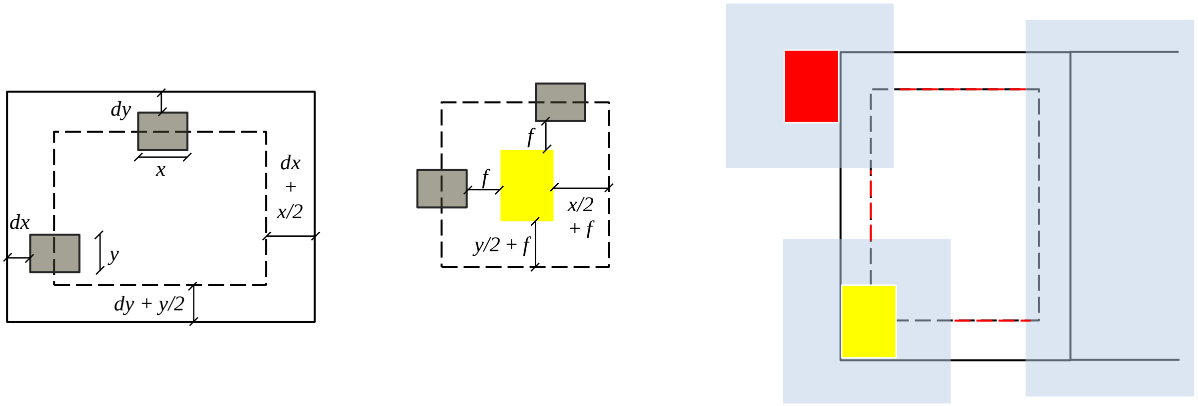
3.2.3 Placing Furniture Inside Each Zone

After sampling the size of a furniture item, we place it inside its corresponding zone by determining the coordinate of its center as shown in Figure 5. In Figure 5a, dx and dy are the distances between a furniture item and the boundaries of the zone (black solid lines), the black dashed lines represent possible placements of the furniture item's center, for furniture against a wall (*TR 5*), $dx = dy = 0$m. Besides, we must consider *TR 6,* so the effects of other furniture and rooms are described as obstacle areas shown in Figure 5b, where the yellow rectangle represent a furniture item, room or connected zone (to keep distance from furniture inside the zone), f is the minimal distance between the yellow rectangle



a) b) c) d)

Figure 4. Principles of alignment (resting zone is blue, living zone is red, cooking zone is green, toilet is orange and bathroom is purple): (a) alignment when zones are parallel to resting zone, (b, c and d) alignment when living zone is perpendicular to resting and cooking zones



a) b) c)

Figure 5. Methodology of placing furniture item inside a zone: (a) possible placements without considering obstacles, (b) obstacle area (b) possible placements considering all obstacles

and the furniture (if the yellow rectangle is a zone, f = 0.3m, otherwise, f = 0.6m). The possible places of the furniture item's center is in the relative complement of black dashed lines in the union of all obstacle areas (Figure 5c).

Therefore, all furniture items are placed by following the procedure below:

1. *List original obstacles including rooms and other zones which are connected with this zone;*
2. *For a furniture item to be placed, sample its size based on SR 5 and 6;*
3. *Considering the furniture can be placed horizontally or vertically, we determine x and y;*
4. *Calculate all obstacle areas;*
5. *If the furniture item is not against a wall, sample dx and dy, otherwise dx = dy = 0;*
6. *Calculate possible placements of the furniture item according to* Figure 5;
7. *Decide the furniture item's placement;*
8. *Add the placed furniture item to the obstacles list and go back to step 2.*

4 Generation Results

The generator is built using Python3. For showing generated floorplans, we sample 1000 times, of which 966 succeeded. The 34 failure cases are caused by the fact that living zones are too small to place the sofa-TV set. All successful samples are shown in this website [24]. We picked two generated floorplans randomly shown in Figure 6. In Section 5, we will describe how to convert a floorplan to 3D indoor scene and how to generate resident's paths with both of them.

We also test the performance of our generator on Intel(R) core(TM) i7-7770 CPU @ 3.60GHz. The generator works 1 million times on average 435.5 seconds with a 96% successful ratio. In the average 959311 successful samples, there are only average 49.2 same floorplans.

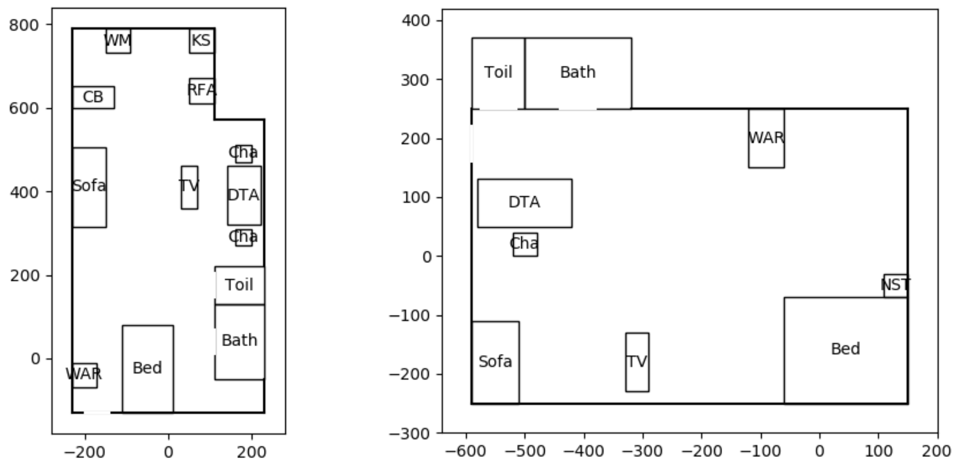


Figure 6. Two generated floorplans (unit: cm, WAR: wardrobe, NST: nightstand, DTA: dining table, CHA: chair, KS: kitchen stove, CB: cupboard, RFA: refrigerator, WM: wash machine, Toil: toilet, Bath: bathroom)

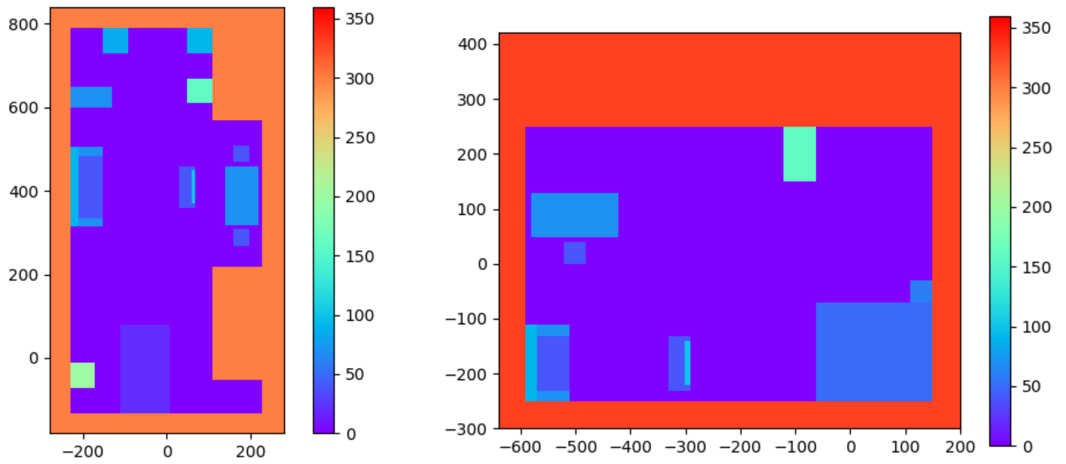


Figure 7. Height functions of two generated houses (unit: cm)

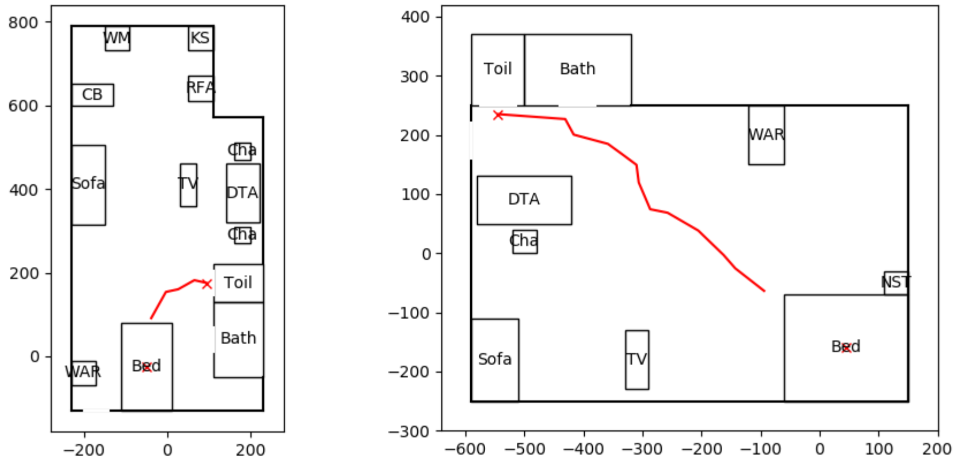


Figure 8. Generated resident's paths from bed to toilet (unit: cm)

5 Utilization of Floorplans

With a floorplan, we can produce a 3D indoor scene with the height function and generate the paths of resident if we know the start and destination points.

5.1 3D Indoor Scene Generation

The 3D scene of a room can be described as a 2D semantic map with the height function if we assume that 3D models of the furniture inside the room are simplified as a combination of cubes. We assume the floor is in the $\mathbf{z} = 0$ plane of the 3D coordinate system. For furniture items, their height functions equal the heights of their upper surfaces (we assume all of their lower surfaces are in the $\mathbf{z} = 0$ plane). For the floor, its height function is equal to 0. For the toilet, bathroom and external areas, their height functions are equal to the floor height of the house.

After sampling the floor height and heights of all the furniture, the 3D indoor scene is defined. Figure 7 shows the 3D scenes of the two virtual houses with their height functions.

5.2 Resident's Path Generation

Using Rapidly exploring Random Tree Star (RRT*) algorithm, the paths for the resident from the bed to toilet are generated in Figure 8. It reveals that the floorplan has a huge impact on resident's paths, the two paths shown in Figure 8 are quite different despite the fact that they have semantically the same starting point and destination. In the future, we will try different algorithms to generate paths for a more realistic simulation.

6 Summary

A small mobile robot is an amazing option for monitoring the health condition of elderly people living alone. However obstacles inside the house such as walls and furniture may obstruct the robot from tracking resident and disturb its observation. Therefore, it is necessary to optimize the design and operation policies of the robot considering the influence of the indoor space. We hope evaluate the influence and optimization by simulation.

This paper proposes an automatic floorplan generator as a first step in our simulation. This generator is efficient and lightweight, which produces diverse and realistic floorplans. With the generated floorplans, indoor 3D scenes are defined after sampling the floor heights and heights of furniture items. Moreover, the paths of the resident moving from starting points to destinations can be generated.

For the next step, we will generate a resident's daily activities and movements in different indoor 3D scenes. This requires studying daily activities schedules of the elderly and the characteristics of elderly pedestrians. With the schedule, we know when the elderly do some activities, when they move and the starting points and destinations of the movements. With the study of elderly pedestrians, we can grasp the position of body joints during his/her movement, these information will be useful in the simulation.

We will then simulate a virtual robot with a Kinect sensor, and produce virtual sensor records. Finally, we will evaluate the influence of indoor spaces and optimize the robot's design and operation policies based on produced models and sensor records.

In these studies, diverse indoor scenes will help us draw statistical conclusions compared with only researching limited indoor spaces. Massive sensor records are also necessary for machine learning algorithms. These are advantages of our floorplan generator.

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