Design and Implementation of a Simulator to Emulate Elder Behavior in a Nursing Home

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Abstract—Many countries are facing the aging problem caused by the growth of the elderly population. *Nursing home (NH)* is a common solution to long-term care for the elderly. This paper develops a simulator to model elder behavior in an NH, which considers public areas where elders interact and imitates their general, group, and special activities. Elders have their preferences to decide activities taken by them. The simulator takes account of the movement of elders and abnormal events. Based on the simulator, two seeking methods are proposed for caregivers to search lost elders efficiently, which helps them fast find out elders who may incur accidents.

Index Terms—activity, elder behavior, nursing home, search, simulator.

1 Introduction

Today, aging is a big challenge in most countries. The rate of population aging is much faster than in the past. According to WHO's report [1], the percentage of the world's population over 60 years will rise from 12% to 22% during 2015–2050. Every one of six people in the world will be aged 60 years or over in 2030. By 2050, the world's population of people aged 60 years and older will increase to 2.1 billion. Governments face the problem of long-term care for the elderly.

Since home-based care requires lots of manpower, *nursing homes (NHs)* are a common alternative to long-term care [2]. NHs are facilities used for the residential care of elders, which are fit for elders who need not stay in hospitals, but cannot be cared for at home. NHs have caregivers on hand 24 hours every day to take care of elders. There are various types of NHs. Some NHs specialize in wheelchair-bound or bedridden elders, where elderly activities are largely restricted by caregivers. This paper targets the NHs with many *independent* elders, which can move and take most activities by themselves without much assistance from caregivers.

In an NH, lost elders (i.e., their whereabouts cannot be grasped by caregivers) may cause accidents due to health or cognitive factors. Searching for the lost elders usually takes a long time, which raises their risk of accidents. In fact, the searching procedure can be facilitated and expedited if we know where these elders took activities in the recently past. In this way, caregivers can fast find out (and rescue) elders who would incur accidents. With the above motivation, the purpose of this paper is to develop a simulator to emulate the behavior of elders in an NH and design seeking methods (via the simulator) to help caregivers search lost elders efficiently.

In this paper, we propose a graphical simulator to show the layout of an NH and how elders take activities in different areas of the NH. Our NH simulator has four features:

- Each elder has his/her preference that influences activities he/she takes. This feature reflects different personalities of elders (e.g., like indoor or outdoor activities).
- Elders can partake in group activities, such as chatting and playing chess. This feature imitates the interaction between elders in the NH.
- We simulate the physiological needs of elders, including drinking water, going to toilets, and dining. This feature makes the simulation closer to the actual life of elders.
- We imitate abnormal events encountered by elders (e.g., fall, sleepwalking, and lost) and dispatch caregivers to find them. This feature can help evaluate the amount of time taken by caregivers to rescue or search the elders.

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Moreover, we design two seeking methods to help caregivers look for lost elders more efficiently, which take account of the most common accident areas for the elderly and the areas where elders took activities recently.

This paper is outlined as follows: Section 2 gives related work. Section 3 details our NH simulator. In Section 4, we propose the seeking methods and the *graphical user interface (GUI)*. Section 5 gives simulation studies. Lastly, Section 6 concludes this paper and discusses future work.

2 Related Work

Many NH-related studies apply the Internet of Things (IoT) technology [3] to help improve the quality of long-term care, which can be divided into four categories.

Service: In [4], an Android-based system is proposed to let elders control appliances and call caregivers via voice commands. The work [5] uses mobile phones to notify elders of taking medicines by messages, voices, and videos. He et al. [6] discuss the demand of mobile health application for information management of senior chronic pain in NHs.

Monitoring: The study [7] proposes an open-source NH monitoring system to collect sensing data and perform actions to ensure elderly safety. The work [8] monitors vital signs of elders (e.g., pulse and respiratory rates) and informs caregivers by mobile phones when detecting deteriorate in health conditions of elders. In [9], sensors are put on elders' legs to detect their bed-exit behavior and check if they fall. The study [10] adopts smart footwear to detect the walking behavior of elders and warns caregivers about possible risks.

Analysis: The work [11] captures elderly activity patterns by using sensors. If patterns change, alerts are sent to clinicians for analysis. In [12], elders carry sensors to record sleep patterns, which are analyzed to find out sleep problems. The study [13] uses accelerometers on the mattress to track actions of elders on beds, and analyzes sensing data by a convolutional neural network. The detection schemes for elderly behavior based on deep learning is surveyed in [14].

Tracking: In [15], a beacon-based middleware model is proposed for localization systems to track elders in NHs. Fong et al. [16] embed wireless transceivers in the clothing of elders for tracking them through mobile access points. Hu et al. [17] employ mobile robots equipped with LoRa devices to track elders, which copes with the uncertainty caused by the elder's movement by using the Doppler frequency shift.

The above monitoring and tracking methods rely on IoT devices equipped on the elderly. However, IoT devices are usually powered by small batteries [18]. When IoT devices run out of energy and lose signals, caregivers cannot grasp the positions of elders by these methods alone. Hence, it is necessary to propose efficient seeking methods for caregivers to fast search missing elders, to avoid them causing accidents.

How to simulate human behavior is widely discussed. Both [19] and [20] model the mobility of pedestrians in the departure hall of an airport. A behavioral decision method is proposed in [21] to imitate crowded passengers in a waiting hall. The work [22] uses an agent-based model to simulate pedestrians in public spaces, which considers social distancing between people due to COVID-19 epidemic. Some studies [23], [24], [25] aim to model human driving behavior. However, the issue of elder-behavior simulation has not been extensively studied. This motivates us to develop a simulator to emulate the behavior of elders in an NH.

Modeling the behavior of elders is a difficult task in itself. Even though elders may be of the same age and gender, there is diversity in their cognitive and physical functioning. Besides, depending on their preferences, elders would take different activities in different areas at different times in an NH. This makes the simulation more challenging.

The work [26] proposes a probabilistic model to simulate the behavior of an NH's residents, which generates the stochastic interval for each activity through an exponential distribution. In essence, there are three differences between the simulation in [26] and our NH simulator. First, unlike [26] that only gives the duration of activities taken by NH residents, our simulator shows the layout of an NH and how elders take activities in different areas of the NH. Second, elders have their preferences to decide activities taken by them in our simulator, but this issue is ignored in [26]. Third, we design seeking methods for caregivers to search lost elders, and implement the seeking methods on our simulator. These differences highlight the significance of our simulator.

3 Design of The NH Simulator

The NH simulator comprises 7 modules. The *layout* module contains map design and node deployment. The *public areas* module handles seat selection by elders. The *personal preferences* module sets up the attributes of elders to reflect their interests. The *general activities* and *group and special activities* modules take charge of daily and other activities of elders, respectively. The *movement* module models the walking behavior of elders. The *abnormal events* module imitates the accidents of elders and the failure of IoT devices.

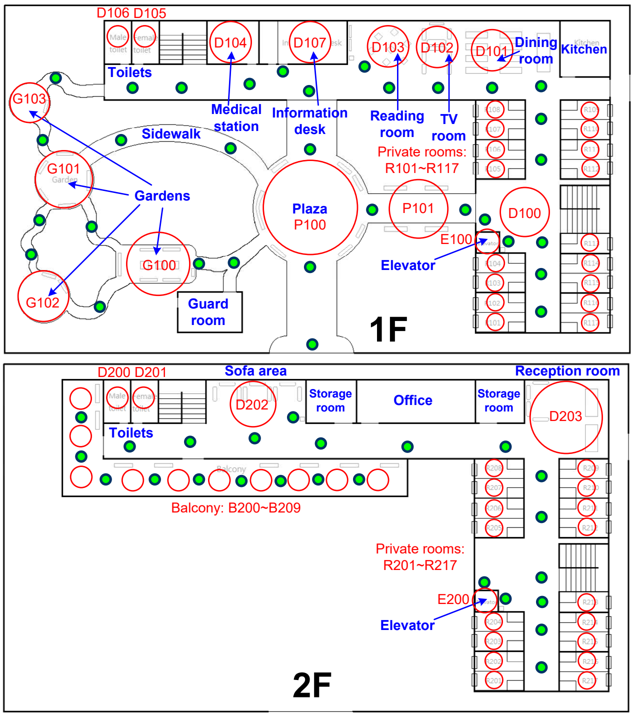


Fig. 1: Map design and node deployment.

3.1 Layout

We consider a two-floor NH with one large yard, as shown in Fig. 1. Most facilities are located on the 1st floor, due to the inconvenient movement of elders. In addition to private rooms and special rooms (e.g., medical station and information desk), the 1st floor has public areas for elders to take activities and interact with each other. For indoors, we plan the reading, TV, and dining rooms. For outdoors, there are gardens, plazas, and sidewalks. The public areas in the 2nd floor include the sofa area, reception room, and balcony.

For management, each area is associated with a *main node* $M_i = \langle \text{ID}_i, f_i, (x_i, y_i), r_i \rangle$, as indicated by a red circle in Fig. 1, where $f_i \in \{1, 2\}$ is the floor number, (x_i, y_i) are the coordinates of the area's center, and r_i is the node's radius (i.e., the area's range). The ID format is one letter followed by three digits, where the letters 'B', 'D', 'E', 'G', 'P', and 'R' mean the balcony, functional areas, elevators, gardens, plazas, and private rooms, respectively. Besides, the 1st digit gives the floor number. Elders will choose main nodes to be their destinations for taking activities. Note that some areas such as the guard room and kitchen are not associated with main nodes, since elders are prohibited to enter these areas. Moreover, we also define *road nodes* to guide people to walk in the NH, which are indicated by green dots in Fig. 1.

3.2 Public Areas

As compared with young people, the activities of elders are simple and regular. On arriving in a public area, elders usually choose preferred seats to do activities. To imitate the seat selection process, each elder is subject to three conditions to decide the seat that he/she chooses: 1) the seat is chosen upon arrival, 2) seat selection is based on the distribution of seats

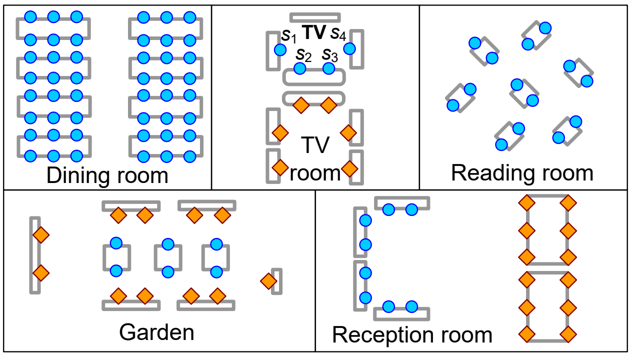


Fig. 2: Seat selection in public areas.

used by others, and 3) seat selection is decided by the activity (e.g., two elders sit face to face for playing chess).

Depending on the public area, the seat selection process is designed as follows (referring to Fig. 2):

Dining room (D101): Each table has 6 seats for choice. The elder first picks a table occupied by no or 1 person. If no such table can be found, for each table whose seats are not fully occupied, the *selection probability (SP)* of this table is set to 0.75, 0.5, and 0.25 [27], if it is occupied by 2, 3, or more people, respectively. Then, the elder arbitrarily picks an empty seat to sit.

TV room (D102): Elders watch TV in the front row (i.e., blue dots). The study [28] points out that people tend to focus on the screen's center when watching TV. Thus, the choice of front seats depends on the angle facing the TV. We set the SPs for seats s_2 and s_3 to 0.9 (as they directly face the TV) and the SPs for seats s_1 and s_4 to 0.7. On the other hand, rear seats (i.e., orange diamonds) are used for rest or chat, and their SPs are set to 0.5.

Reading room (D103): In this room, each table has two seats facing each other. Elders can read newspapers/books or play chess. If an elder wants to read, he/she first chooses an empty table [29]. Otherwise, the elder picks a seat where the opposite seat is also sat by an elder who is reading. On the other hand, suppose that two elders would like to play chess together. One elder selects an empty table and picks a seat to sit. Then, the other elder sits on the opposite seat.

Garden (G100): When an elder wants to take a break in the garden, he/she prioritizes selecting the seats at the garden's edge (indicated by diamonds). Central seats (indicated by dots) are used to play chess, whose selection rule is the same as that in the reading room.

Reception room (D203): There exist sofa seats (i.e., dots) and seats in large tables (i.e., diamonds). Elders prefer sofa seats as they are more comfortable.

As for other public areas, their functions are relatively single, or there is no special condition between the seats that affects the choice of the elderly. Thus, elders will randomly choose seats in these areas.

3.3 Personal Preferences

Each elder is assigned a *preference list (PL)* to decide his/her interests to take general activities, as shown in Tables 1 and 2. Indoor activities include watching TV, reading newspapers or books, and resting in private rooms. Regarding outdoor activities, an elder can go to plazas, gardens, or the balcony. We design five styles of PLs to reflect different personalities of the

TABLE 1: PLs for indoor (general) activities.

Style 1	TV	+	-	Read	+	-	Rest	+	-
Daytime	80	2	8	60	4	6	70	3	7
Evening	70	3	7	80	2	8	60	4	6
Nighttime	5	0	5	5	0	5	95	3	1
Style 2	TV	+	-	Read	+	-	Rest	+	-
Daytime	50	5	5	50	5	5	50	5	5
Evening	50	5	5	50	5	5	50	5	5
Nighttime	5	0	5	5	0	5	95	3	0
Style 3	TV	+	-	Read	+	-	Rest	+	-
Daytime	20	8	2	30	7	3	40	6	4
Evening	40	6	4	30	7	3	20	8	2
Nighttime	5	0	5	5	0	5	95	3	1
Style 4	TV	+	-	Read	+	-	Rest	+	-
Daytime	40	6	4	30	7	3	20	8	2
Evening	70	3	7	60	4	6	80	2	8
Nighttime	5	0	5	5	0	5	95	3	1
Style 5	TV	+	-	Read	+	-	Rest	+	-
Daytime	60	4	6	80	2	8	70	3	7
Evening	30	7	3	20	8	2	40	6	4
Nighttime	5	0	5	5	0	5	95	3	1

TABLE 2: PLs for outdoor (general) activities.

Style 1	Plaza	+	-	Garden	+	-	Balcony	+	-
Daytime	40	6	4	30	7	3	20	8	2
Evening	20	8	2	30	7	3	40	6	4
Nighttime	5	0	5	5	0	5	5	0	5
Style 2	Plaza	+	-	Garden	+	-	Balcony	+	-
Daytime	50	5	5	50	5	5	50	5	5
Evening	50	5	5	50	5	5	50	5	5
Nighttime	5	0	5	5	0	5	5	0	5
Style 3	Plaza	+	-	Garden	+	-	Balcony	+	-
Daytime	60	4	6	80	2	8	70	3	7
Evening	80	2	8	70	3	7	60	4	6
Nighttime	5	0	5	5	0	5	5	0	5
Style 4	Plaza	+	-	Garden	+	-	Balcony	+	-
Daytime	60	4	6	70	3	7	80	2	8
Evening	30	7	3	20	8	2	40	6	4
Nighttime	5	0	5	5	0	5	5	0	5
Style 5	Plaza	+	-	Garden	+	-	Balcony	+	-
Daytime	30	7	3	35	6	4	20	8	2
Evening	60	4	6	70	3	7	80	2	8
Nighttime	5	0	5	5	0	5	5	0	5

elderly: 1) liking indoor activities, 2) neutral, 3) liking outdoor activities, 4) liking outdoor activities in the daytime and indoor activities in the evening, and 5) liking indoor activities in the daytime and outdoor activities in the evening. Besides, we divide a day into three periods: *daytime* (6:00–18:00), *evening* (18:00–21:00), and *nighttime* (21:00–6:00). The preferences of an elder may change in different periods.

In Tables 1 and 2, each activity α_i has a 3-tuple value (b_i, u_i, d_i), where b_i is the base value, and u_i and d_i are small integers to adjust b_i (i.e., numbers in columns '+' and '-'). If an elder picks activity α_i, the simulator produces a random number between 0 and 100, as denoted by $\zeta_{\texttt{rand}}(100)$. When $\zeta_{\texttt{rand}}(100) \leq b_i$, the elder takes activity α_i. Otherwise, the elder chooses another activity (using the same rule). Hence, larger b_i implies that the probability for the elder to take activity α_i is higher. To avoid the elder repeatedly engaging in the same activity too many times, after the elder finishes activity α_i, we change the base value by $b_i = b_i - \zeta_{\texttt{rand}}(d_i)$. Besides, the base values of other activities are updated by $b_j = b_j + \zeta_{\texttt{rand}}(u_j)$. For example, in style 1 (daytime), the base value of watching-TV activity is set to 80. Suppose that the elder chooses this activity. After he/she finishes watching TV, the base value of watching-TV activity is $80 - \zeta_{\texttt{rand}}(8) = 80 - 5 = 75$. On the other hand, when the elder chooses to read, the base value of watching-TV activity changes to

$80 + \zeta_{\mathtt{rand}}(2) = 80 + 1 = 81$. The base value of each activity will be reset to its initial value every six hours.

3.4 General Activities

Three states are related to general activities of elders: *idle*, *moving*, and *acting*. When an elder is idle, the elder picks an activity to take based on his/her PL. If the elder is not in the target area (to engage in the selected activity), the state changes to moving, and the elder keeps walking toward the destination (e.g., a seat in the target area), as discussed later in Section 3.6. On arriving at the destination, the elder starts the activity. Thus, the state switches to acting, and a counter is set to regulate the activity's duration. Once the counter expires, the elder's state returns to idle, and the elder would pick the next activity to take (possibly the same activity).

Some activities may have multiple target areas. Hence, each target area is associated with an SP for elders choosing to engage in their activities: 1) *watch TV:* D102 (SP: 1), 2) *read:* D103 (SP: 0.6) and D202 (SP: 0.4), 3) *rest:* the elder's private room (SP: 1), 4) *go to plazas:* P100 (SP: 0.7) and P101 (SP: 0.3), 5) *go to gardens:* G100, G101, G103 (each SP: 0.3), and G102 (SP: 0.1), 6) *go to the balcony:* B200–B209 (each SP: 0.1).

Moreover, the duration of each activity is set as follows: 1) *watch TV:* 20–40 min, 2) *read:* 10–20 min, 3) *rest:* 210–300 min (nighttime) and 30–70 min (others), 4) *outdoors (i.e., plazas, gardens, balcony):* 10–30 min.

3.5 Group and Special Activities

We define two types of group activities: *chatting* and *playing chess*. If an elder wants to take a group activity, he/she asks whether a neighbor would like to chat or play together. The 3-tuple value for group activities is set to $(10, 9, 1)$ in each PL style, so every elder has the opportunity to partake in group activities. For chatting, elders randomly pick the TV room (D102), reception room (D203), sofa area (D202), balcony (B200–B209), plazas (P100–P101), or gardens (G100–G103) to be their target areas. The duration of a chat is 10 to 50 minutes. For playing chess, the target areas contain the reading room (D103) and garden (G100), where their SPs are set to 0.7 and 0.3, respectively. Besides, the duration of playing chess is 20–60 minutes.

For special activities, we consider *drinking water*, *going to toilets*, and *dining*. When an elder wants to drink water or go to the toilet, the elder suspends the current activity and engages in that activity. After completing drinking water or using the toilet, the elder resumes the previous activity if its counter has not expired yet. In particular, we set four water dispensers in areas D101, D103, D202, and D203. Whenever an elder feels thirsty, he/she walks toward the closest water dispenser. The elder can choose four public toilets in areas D105, D106, D200, and D201, besides the toilet in his/her private room. Once the elder is far away from his/her private room, he/she selects the nearest (unused) public toilet. The activity duration of drinking water and using toilets is set to 1–3 and 4–9 minutes, respectively.

In an NH, meal times are usually fixed, so we set breakfast, lunch, and dinner times at 8:00, 12:00, and 17:30, respectively. If the meal time is up, but the residual time of the current activity exceeds 30 minutes, we shorten it to [1, 30] minutes. After finishing the current activity, the elder goes to the dining room (D101). The duration of dining is 15–30 minutes. Then, the elder will pick a new activity to take.

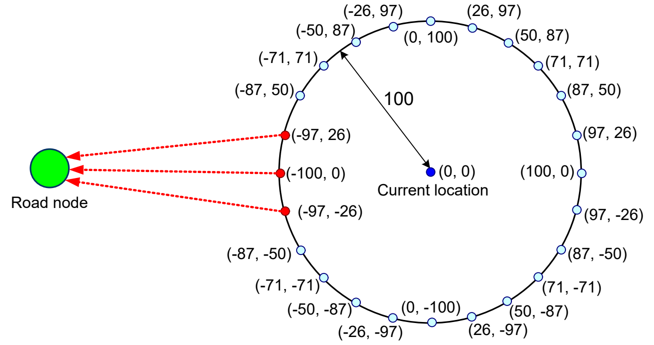


Fig. 3: Non-linear movement model, where the circle's radius is 100.

3.6 Movement

In reality, everyone does not walk at the same speed. Hence, each elder is assigned a speed parameter v_j, where $50 \leq v_j \leq 100$. Let $S^{\max}_{\mathtt{sys}}$ be the *maximum movement distance per step (MMDS)*. Then, the elder's MMDS is defined by $S^{\max}_{j} = S^{\max}_{\mathtt{sys}} \times v_j/100$. For example, suppose that $S^{\max}_{\mathtt{sys}} = 40$ units and $v_j = 80$. Thus, the elder's MMDS is $40 \times 80/100 = 32$ units. Even for the same elder, the sizes of his/her steps are also different. Hence, we estimate the size of each step by

$$s_{j,k} = S^{\max}_{j} \times (70 + \zeta_{\mathtt{rand}}(30))/100. \tag{1}$$

In other words, the step's size $s_{j,k}$ is within $[70\%, 100\%]$ of the elder's MMDS. Take the previous example. The size of each step ranges from $22.4 (= 32 \times 70\%)$ units to 32 units.

When an elder picks an activity to take but is not in the target area, the elder moves toward that area. As mentioned in Section 3.1, road nodes (i.e., green dots in Fig. 1) are deployed on maps to guide the elder. Here, we adopt the A* algorithm [30] to choose road nodes, which estimates a cost for each road node n_k by $S(n_k) = C(n_k) + H(n_k)$, where $C(n_k)$ is the actual cost from the current road node to n_k, and $H(n_k)$ is the predicted cost from n_k to the main node of the target area. Then, A* picks the adjacent road node with the smallest cost to move, and updates $C(n_k)$ and $H(n_k)$ of other road nodes, until the elder reaches the target area.

However, the elder will not move to the next road node directly. Instead, we employ the *non-linear movement model* to simulate the walking behavior of elders. Specifically, we draw a circle whose center is the elder's current location and radius is $s_{j,k}$ (i.e., the step's size), and take 24 coordinates equidistantly on the circumference. Fig. 3 gives an example, where the circle's center is set as the origin and the radius is 100. These coordinates will be scaled proportionally according to $s_{j,k}$. For example, the coordinates $(100, 0)$ is changed to $(40, 0)$ if $s_{j,k} = 40$. Then, the elder picks one of the three coordinates on the circumference closest to the road node, and strides his/her step to the selected coordinates. Once the distance between the road node and the current location is below $s_{j,k}$ (i.e., the road node is within the circle), the elder directly strides his/her step to the road node.

3.7 Abnormal Events

As discussed in Section 2, many studies let the elderly carry IoT devices to monitor their health statuses and locate them. Thus, we simulate two types of abnormal events related to IoT devices. One is the abnormal physiological state/behavior of elders reported by IoT devices (e.g., fall, high blood pressure, and sleepwalking). Here, the *triggering probabilities (TPs)* of this type of event in private rooms, indoor activity areas, public toilets and the balcony, outdoor activity areas, plazas, and other areas are set to 0.8, 0.5, 0.4, 0.3, 0.2, and 0.1, respectively. Since older people are more prone to accidents, the TP is slightly adjusted based on his/her age (that is, the older the age, the higher the TP). When the event is fall or high blood pressure, the elder stays at the current location. If the event is sleepwalking, the elder wanders aimlessly. In this case, a caregiver will directly go to the elder's location and bring him/her to the medical station (D104).

The other type of event is the failure of IoT devices. The TPs of such events are small (e.g., 0.005–0.03), independent of the locations and ages of elders. In this situation, the elder is treated as a lost one, even if he/she is still engaging in an activity. Thus, the caregivers will search that elder (as he/she may incur accidents) by the seeking methods in Section 4. Note that this module is optional and can be turned off.

3.8 Configuration and Input Data

We adopt the Microsoft EXCEL to store configuration and input data. There are three configuration files:

1) *Node.xlsx:* It records the IDs, floor numbers, coordinates, and radii of main nodes, and the IDs, floor numbers, and coordinates of road nodes, as discussed in Section 3.1. Users can add main nodes to define new areas or rooms. If a main node is removed, elders are forbidden to enter that area or room. Moreover, users can add or remove road nodes to change the moving paths of elders.

2) *Preference.xlsx:* It records the PL styles for elders in Section 3.3. There are five default PL styles, as Tables 1 and 2 show. Users can add PL styles based on their needs.

3) *Activity.xlsx:* It records the type (i.e., general, group, and special), target areas, SPs, and duration of each activity. As mentioned earlier in Sections 3.4 and 3.5, an activity can have multiple target areas. In this case, each target area is associated with an SP. Users can also define new activities.

All configuration files have built-in values, so NH managers or caregivers can use the simulator without inputting configuration data (unless they want to define their nodes, PL styles, or activities).

To start the simulator, users need to set up the attributes of elders in the "Elder.xlsx" file. The attributes of an elder include the name, sex, age, speed parameter (i.e. v_j), private room, and PL style. To reduce the burden of inputting these data, the file has five default settings of elder attributes, as presented in Table 3. Hence, NH managers or caregivers can easily add elders in the simulator by copying (and changing) these default settings.

4 SEEKING METHODS AND GUI

We design two seeking methods for caregivers to find lost elders. In the *high-possibility-area first seeking (HFS)* method, the areas in the NH are assigned with fixed priorities. Then, a caregiver visits each area to search a lost elder e_j based on its priority. According to the statistics in [31], the most common place for elderly accidents to happen is indoors, especially in bedrooms and bathrooms. Thus, the search order of HFS is privates rooms, indoor areas, and outdoor areas.

The *two-stage activity-based seeking (TAS)* method assumes that the activities of the elderly are usually regular. Let $\hat{\mathcal{A}}_0$, $\hat{\mathcal{A}}_1$, and $\hat{\mathcal{A}}_2$ contain the areas that e_j took activities in the recent two hours, the same period the day before, and the same period two days ago, respectively. For each area a_i in $\hat{\mathcal{A}}_0$, $\hat{\mathcal{A}}_1$, and $\hat{\mathcal{A}}_2$, its priority is set to $w_0 \times \lambda_i$, $w_1 \times \lambda_i$, and $w_2 \times \lambda_i$, respectively, where λ_i is the frequency that e_j took activities in a_i and $w_0 > w_1 > w_2$. Here, we set $w_0 = 5$, $w_1 = 2$, and $w_2 = 1$. After that, in the first stage, the caregiver searches e_j in the areas of $\hat{\mathcal{A}}_0 \cup \hat{\mathcal{A}}_1 \cup \hat{\mathcal{A}}_2$. However, if e_j cannot be found, the caregiver looks for e_j in other areas in the second stage. Based on the statistics of areas in $\hat{\mathcal{A}}_0 \cup \hat{\mathcal{A}}_1 \cup \hat{\mathcal{A}}_2$, when e_j took more indoor activities, the caregiver visits indoor areas first. Otherwise, he/she searches e_j in outdoor areas first.

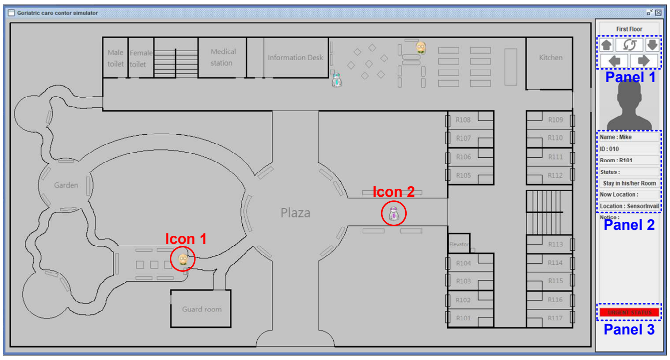


Fig. 4: GUI of the NH simulator.

TABLE 3: Settings of elder attributes in the simulation.

Name	Sex	Age	v_j	Room	PL
Mike	Male	73	81	R101	Style 1
Don	Male	70	88	R103	Style 2
George	Male	65	95	R212	Style 3
Julia	Female	68	91	R207	Style 4
Winnie	Female	71	85	R115	Style 5

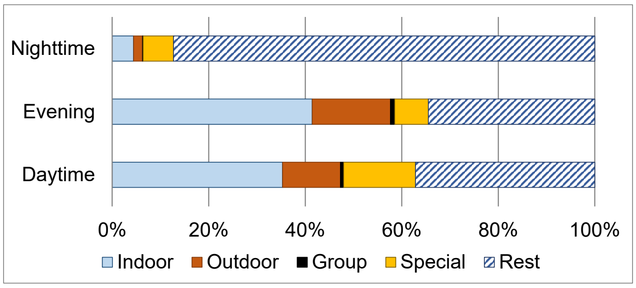
Fig. 4 shows the GUI of our NH simulator. There are two types of moveable icons on the map, where one represents elders (i.e., icon 1) and the other indicates caregivers (i.e., icon 2). Each elder icon will move and take activities based on the elder's PL discussed in Section 3.3. Once an elder is lost, two caregiver icons appear, which simulates caregivers to search the lost elder. One caregiver uses the HFS method to find the elder, while the other caregiver does so through the TAS method.

There are three panels located on the GUI's right side. Panel 1 is the control panel, where a user can change the floor number by the up and down arrows. The loop icon is used to toggle whether to display main nodes. The left and right arrows are used to switch the information about different elders, as shown in panel 2. More concretely, the information includes the name, ID, private room number, activity status, and positioning data of the selected elder. When the elder incurs an accident (as discussed in Section 3.7), panel 3 will be displayed with a red background as a reminder.

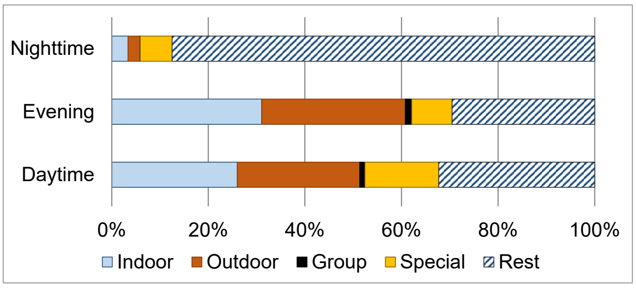
5 SIMULATION STUDIES

In the simulator, we set up five elders, whose attributes are given in Table 3. The MMDS $S_{\text{sys}}^{\max}$ is 40 units, and each elder has a speed parameter v_j to control his/her walking behavior. Besides, each elder is assigned a different PL style to reflect different personalities, as mentioned in Section 3.3.

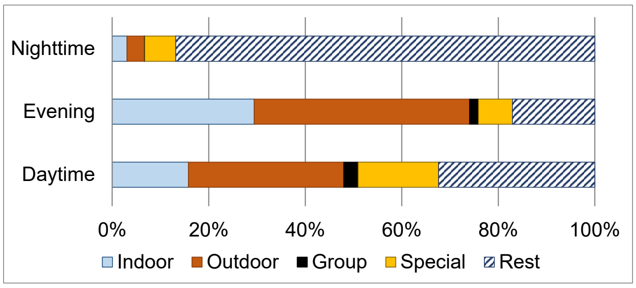
Experiment 1 is to verify whether each elder's activities will be carried out according to his/her PL, where we evaluate



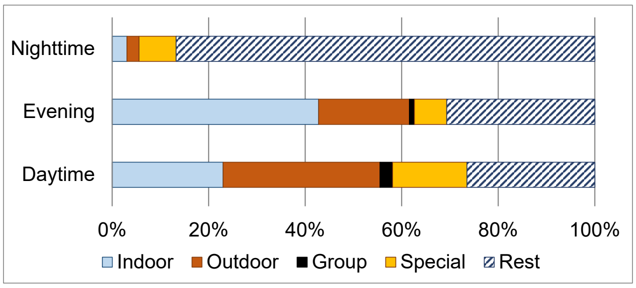
(a) Mike (PL style 1)



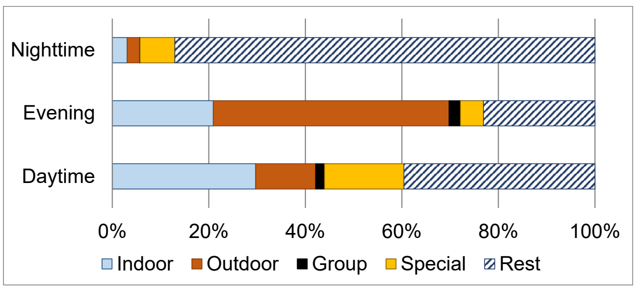
(b) Don (PL style 2)



(c) George (PL style 3)



(d) Julia (PL style 4)



(e) Winnie (PL style 5)

Fig. 5: The proportion of time spent on different activities.

the proportion of time spent on different types of activities by each elder. The simulation duration is 10 days, where each day will start at 6:00. To avoid accidents interfering with the daily routine of an elder (thereby affecting the experimental result), the abnormal events module is turned off.

TABLE 4: The proportion of time spent on inactivities.

Name	Daytime	Evening	Nighttime
Mike	64.03%	63.07%	90.34%
Don	53.10%	54.22%	89.75%
George	43.34%	41.82%	88.85%
Julia	49.78%	60.94%	88.93%
Winnie	58.59%	49.89%	89.75%

In experiment 2, we measure the amount of time taken by caregivers to search elders, and compare the performance of two seeking methods discussed in Section 4. The abnormal events module is turned on, and each elder will encounter 50 times of abnormal events. The ratio of accidents (i.e., abnormal physiological state/behavior of elders) to IoT device failures (which are treated as lost events of elders) is 2:1.

For both experiments, we perform 20 simulations with different random seeds and take their average.

5.1 Proportion of Activities Taken

Fig. 5 reveals the proportion of time that each elder spends on activities. Five types of activities are shown: indoor (i.e., watch TV and read), outdoor (i.e., go to plazas, gardens, and balcony), group (i.e., chat and play chess), special (i.e., drink water, go to toilets, and dine), and rest in private rooms.

Since elders sleep in the nighttime (21:00–6:00), most non-resting activities are taken in both daytime (6:00–18:00) and evening (18:00–21:00). In general, an elder is said to like indoor activities if he/she takes significantly more time on indoor activities than on outdoor activities, and vice versa (e.g., the difference between the time taken on indoor and outdoor activities overtakes 10%) [32] [33].

For Mike, he spends 35.5% and 12.0% of time on indoor and outdoor activities in the daytime, respectively. Besides, Mike takes 41.5% and 16.2% of time for indoor and outdoor activities in the evening, respectively. The result reveals that Mike likes indoor activities, which matches PL style 1.

For Don, he takes 26.0% and 25.4% of time for indoor and outdoor activities, respectively, in the daytime. During the evening, he spends 31.1% and 29.7% of time on indoor and outdoor activities, respectively. Since Don takes similar time on both indoor and outdoor activities, his preference is neutral, which corresponds to PL style 2.

For George, he spends 32.2% and 44.6% of time on outdoor activities in the daytime and evening, respectively, but merely 15.8% and 29.4% of time on indoor activities in the daytime and evening, respectively. The result reveals that George likes activities outdoors (i.e., PL style 3).

For Julia, she consumes more time on outdoor activities (i.e., 32.5%) than indoor activities (i.e., 23.0%) in the daytime. Moreover, Julia takes less time on outdoor activities (i.e., 18.8%) than indoor activities (i.e., 42.8%) in the evening. Hence, her data matches PL style 4.

For Winnie, she takes more time on indoor activities (i.e., 29.7%) than outdoor activities (i.e., 12.4%) in the daytime. She also spends more time on outdoor activities (i.e., 48.8%) than indoor activities (i.e., 20.9%) in the evening. The result reveals that Winnie's data matches PL style 5.

From the result in Fig. 5, we demonstrate that our NH simulator can correctly reflect an elder's interest in terms of taking different activities according to his/her PL.

The statistical result in the study [34] points out that the elderly in an NH spend around 45%–77% of their time

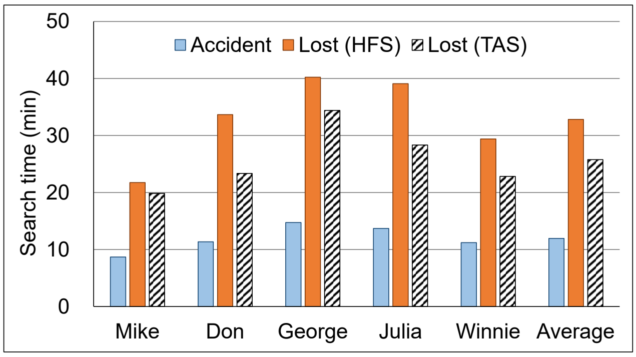


Fig. 6: Comparison of search time.

on *inactivities*, like doing nothing, resting, and watching TV. Hence, we measure the amount of time that each elder spends on both watching TV and resting in the daytime, evening, and nighttime, as listed in Table 4. Since Mike likes indoors activities (i.e., PL style 1), among all elders he consumes the most time on inactivities. As can be seen, the data in Table 4 for both daytime and evening is not much different from the statistical result in [34]. As mentioned earlier, elders sleep in the nighttime, so the proportion of time spent on inactivities for each elder will exceed 88%.

5.2 Search Time

Fig. 6 presents the amount of time spent by a caregiver to search each elder. For accidents, as the IoT devices on elders function well, caregivers can track elders and directly move to their locations. On the contrary, for lost events, IoT devices have no signals (e.g., broken). Hence, caregivers have to look for elders through a seeking method. That explains why the search time of accidents is shorter than that of lost events.

As shown in Fig. 1, the range for caregivers to search elders outdoors is larger than indoors. When an elder prefers outdoor activities (i.e., PL style 3) or takes more activities outdoors in daytime (i.e., PL style 4), a caregiver spends more time to walk to the elder's location. Thus, for accidents, the search times for George and Julia (with PL styles 3 and 4, respectively) are larger than others.

Regarding lost events, we compare search times by using the HFS and TAS methods. HFS lets caregivers search private rooms first, followed by indoor areas and outdoor areas. In TAS, caregivers prioritizes finding lost elders at their recently past locations. Because Mike likes indoor activities (i.e., PL style 1), HFS's policy makes the caregiver fast find out Mike. Therefore, HFS's search time is similar to that of TAS (for Mike). For other elders, since they take relatively more activities outdoors, TAS can have shorter search time than HFS. On average, TAS saves 21.5% of search time, as compared with HFS.

6 Conclusion and Future Work

NH is a common solution to long-term care for the elderly. This paper develops a simulator to emulate the behavior of elders in an NH. It has seven modules to deal with the NH's layout, public areas, personal preferences, activities, movement, and also abnormal events. Based on this NH simulator, we propose the HFS and TAS methods to help caregivers search for lost elders. HFS first searches the most common accident areas for the elderly, while TAS prioritizes seeking the areas where elders recently took activities. With experiments on the NH simulator, we show that two objectives have accomplished. First, our simulator can effectively imitate the behavior of the elderly, where the proportion of each elder taking on indoor and outdoor activities meet his/her PL. Besides, the simulator can also simulate group activities (i.e., chatting and playing chess) and special activities (i.e., drinking water, going to toilets, and dining). Second, since TAS has a shorter search time than HFS, we demonstrate that the search process can be expedited if caregivers know where lost elders ever took activities in the recent past. This could help caregivers fast rescue elders who may incur accidents.

The NH simulator has some limitations, which we will improve as future work. First, only one-on-one interactions are allowed in group activities, where an elder can chat or play chess with just one elder. We will consider multi-person chat and other group activities to let more than two elders partake in. Second, each elder can move to any main or road nodes. In practice, some elders may have limited mobility (e.g., in wheelchairs). To simulate their behavior, we will restrict main and road nodes to which they can move based on their positions. Third, we currently build the searching application on the simulator. In the future, we will develop more applications. For example, we can add moveable furniture to the simulator, which helps NH managers arrange furniture based on the activities of elders. Moreover, we can find hotspots in the NH where many elders passed or took activities, which could help researchers pick good positions to place sensors for monitoring. Lastly, we will plan to collect data (e.g., preferences and interactions of elders) in real NHs as reference to further improve our simulator.

Appendix

We list the detailed activities of each elder discussed in Section 5.1 during one day, where the first day is taken as the representative. The format is "[start time] activity (time water/toilet)", where the parentheses indicate when the elder goes to drink water or use the toilet (if occurred). Different activities are separated by semicolons.

Mike: [6:00] rest (7:03 toilet); [8:11] dine; [8:32] rest (9:10 toilet); [10:07] in plaza (10:26 water); [10:16] play chess; [10:47] read; [12:08] dine; [12:37] rest (12:40 toilet); [14:46] watch TV (15:13 toilet); [15:58] rest (16:29 water); [17:02] read; [17:32] dine (17:53 toilet); [18:08] chat; [19:01] in plaza; [19:27] read; [20:39] watch TV (21:17 water); [21:37] in balcony; [21:54] rest (23:21 toilet).

Don: [6:00] rest (6:57 toilet); [7:05] chat; [8:09] dine; [8:42] watch TV; [9:31] in garden; [9:57] rest (10:38 toilet); [11:28] read (11:43 water); [12:12] dine; [12:50] in plaza; [13:26] rest (13:55 toilet); [15:03] in balcony; [15:47] read; [16:06] play chess; [16:58] in plaza; [17:36] dine; [18:08] chat; [19:01] in garden (19:09 toilet); [19:56] read (20:25 water); [21:00] rest; [21:55] in balcony; [22:33] watch TV (22:50 toilet); [23:32] rest.

George: [6:00] rest (6:15 toilet); [7:46] in balcony; [8:24] dine; [9:05] in garden (10:27 water); [10:36] watch TV (11:11 toilet); [11:16] in balcony; [12:26] dine; [13:18] in plaza; [13:34] in garden; [14:48] read (15:04 toilet); [15:26] watch TV; [16:06] play chess; [16:58] rest; [17:31] dine; [18:03] in balcony (18:33 toilet); [18:37] in plaza; [19:00] watch TV (19:49 water); [20:34] chat; [21:03] in balcony; [21:43] watch TV (22:12 toilet, 22:23 water); [22:41] rest.

Julia: [6:00] rest; [6:30] in balcony (6:50 water); [7:05] chat; [7:36] read; [8:20] dine (8:43 toilet); [9:21] in garden; [10:16] play chess; [10:47] rest; [11:19] watch TV; [12:21] dine; [12:49] in plaza (13:08 toilet); [13:29] chat; [14:20] in balcony; [14:55] watch TV (15:35 water); [16:32] read (17:20 toilet); [17:40] dine; [18:15] rest; [20:34] chat; [21:03] read (21:25 toilet); [21:28] watch TV; [22:06] rest (22:30 water, 23:20 toilet).

Winnie: [6:00] rest (7:30 toilet); [8:12] dine; [8:38] in plaza; [9:17] in balcony (9:27 water); [10:02] in garden; [10:48] read; [11:16] rest (11:28 toilet); [12:15] dine; [12:43] rest; [13:29] chat; [14:20] read (14:48 toilet); [15:15] watch TV (16:06 water); [16:29] rest; [17:18] read; [17:35] dine (18:03 toilet); [18:49] read; [19:21] in plaza; [19:41] rest; [21:01] in balcony; [21:55] watch TV (22:31 toilet); [23:26] rest (23:47 water).

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