

# A Method for Pedestrian Position Estimation using Inter-Vehicle Communication

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**Abstract**—In this paper, we propose a method for detecting the positions of pedestrians by cooperation of multiple cars with directional antennas to support drivers for pedestrian safety. In the method, each pedestrian carries a device which periodically transmits a beacon with a unique ID, and each car passing near the pedestrian receives the beacon by a directional antenna and measures the distance and the angle of arrival. We assume the distribution of the measurement errors to be a normal distribution, and the system calculates the existence probabilities of each pedestrian at each point. By exchanging information of the probabilities between cars, the area with high existence probability is narrowed down. In this paper, we first describe the situations where detecting positions of pedestrians greatly contribute to pedestrian safety, and then we describe the probability model used in our method, the method for calculating existence probabilities from information from multiple cars, and the protocol for exchanging the probability information between cars. We evaluated our method on QualNet simulator, and confirmed that the positions can be detected accurately enough for practical uses.

## I. INTRODUCTION

In recent years, the number of cars is rapidly increasing in several countries and accordingly the number of traffic accidents is rapidly increasing. In Japan, while the total number of fatal traffic accidents is decreasing, there is only modest decrease in the number of traffic accidents where a pedestrian, a bicycle, or a motorcycle is involved [2][3]. This situation could prompt the introductions of AHS(Advanced Cruise-Assist Highway Systems) or ASV(Advanced Safety Vehicle) which warn drivers in dangerous situations, automatically decelerates the car or avoid an obstacle automatically[1]. But, currently these mechanisms only avoid collisions against large objects, and thus some car manufacturing companies are developing mechanisms to detect pedestrians or bicycles. Some of these mechanisms employ sensors installed on a car to detect pedestrians or bicycles[4], [5], [6]. In other mechanisms, devices carried by pedestrians and cars send their positions to another kind of device installed on crossroads, and this device notifies the cars in dangerous situations [4]. The former method has a problem of the dead angle of sensors, and the latter method requires extra costs for installing the devices on crossroads.

In this paper, we propose a method for precisely detecting pedestrians utilizing communication between cars with directional antennas. In the existing methods, the problem of dead

angle cannot be completely eliminated, since the sensed data is only used by the car which sensed the data. In our method, cars send the sensed information to other cars by inter-vehicle communication to solve the dead angle problem and make the result of detection more precise. Our method does not need an extra cost for installing devices on crossroads.

In our method, we assume that each pedestrian carries a device which periodically transmits a beacon signal with a unique device ID. Each car is assumed to have a directional antenna for receiving beacons, a positioning system like GPS, a precise clock (which usually comes with a GPS receiver), a computer with a capability of inter-vehicle communication and road map data. Each car receives the beacon by the directional antenna and measures the distance and the angle of arrival of the beacon. The detected information of the position of the pedestrian has some error. We calculate the existence probabilities at each point by assuming that the distribution of error follows a normal distribution. Then, the probability information is exchanged between cars, and the area with high existence probability is narrowed down by overlapping the information from multiple cars. The probabilities of moving speed of each pedestrian can be also used to make the results more precise.

For evaluation of our method, we conducted some simulations of our method using QualNet simulator. In a crossroad with a lot of obstructions, we counted the number of beacons received by cars until the car reaches the distance needed to stop without crashing into the pedestrian. Then we compared the results with and without inter-vehicle communication. The area of 90% existence probability can be narrowed down from a near-circular area with radius of 18.33m to 3.74m.

## II. RELATED WORKS

Currently, many car companies and researchers are involved in researches for realizing a vehicle safety system using inter-vehicle communication. Misener et al. have proposed and implemented a safety assistance system using inter-vehicle communication. They evaluated their system at a large flat area similar to a runway of airplane and an intersection in the real world[5]. In [4], a system for pedestrians to avoid car accidents is proposed. In this system, pedestrians and cars send information including their positions and moving velocity to a server located on each intersection, and cars receive

attention messages from the server when the server notices that a pedestrian and a car will collide based on the information of position and velocity of the pedestrian and the car. A system for pedestrians to avoid car accidents are also proposed in [6]. In this system, a car sends a information including its position and moving velocity to a device carried by each pedestrian, and this device calculates the positional relation between the pedestrian and the car and sends an attention message to the car when necessary. The former system enables driver to avoid accidents with pedestrians who cannot be viewed from the driver, but this system requires additional costs to install the servers on each intersection. This system also has a problem of large communication delay. The latter system requires pedestrians to carry a device with accurate positioning capability, which is potentially expensive.

In order to detect a pedestrian or an obstacle, these objects have to be recognized and positioned. As for positioning, there are some existing methods utilizing GPS, laser range finders[7] and radio wave[8], [9], [10]. GPS is a popular method of positioning, but its measurement error is as much as 10 meters. The method using a laser range finder cannot detect all objects in a situation with high vehicle density, since there can be dead angle of laser beam. A method using radio waves uses received signal strength or the angle of arrival for estimating positions of objects. This method is not prone to the influence of obstacles, while the measurement error tends to be larger than the method using laser. For any of these method, in order to improve the accuracy of position estimation, putting many anchors, cooperation of many devices, and installing devices on infrastructures are required.

It is known that cars require a certain amount of distance to stop completely[11]. This distance includes the distance while the car runs until the driver pedals the brake. Thus, the notification has to be shown to the driver before the distance between the car and the object becomes closer than the stopping distance, and this is an absolute time restriction for car accident avoidance systems.

### III. TARGET SITUATION OF PEDESTRIAN DETECTION

In this section, we describe the target situations where pedestrian detection and alert systems are needed. According to the white paper published by National Police Agency of Japan [3], 74.6% of traffic accidents occur in urban areas, and 43.5% of them occur in intersections. 25% of the pedestrian fatalities are caused by unreasonable road crossings. According to [11], drivers who have been notified of the existence of pedestrians pedal the brakes about one second earlier.

Therefore, the number of these fatalities can be reduced by giving drivers information about pedestrians who are crossing the road. Following the above discussion, we decided to focus on the following situation as our target.

*A Blind Intersection due to Buildings and Other Vehicles:* Figure 1 denotes a blind intersection due to buildings, roadside trees, and other vehicles. Drivers passing through this intersection cannot see beyond these structures. This is called a blind spot. If a pedestrian tries to get across such an intersection

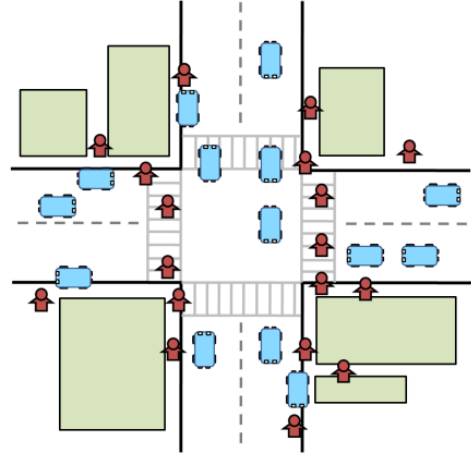


Fig. 1. A Blind Intersection due to Buildings and Other Vehicles

when many cars are slowly moving due to a signal or traffic jam, it is difficult for the drivers to notice pedestrians who are in the blind spots. In such a situation, systems which notify positions of pedestrians to the drivers will certainly reduce the number of traffic accidents.

### IV. PEDESTRIAN POSITION ESTIMATION PROBLEM

In this section, we give some assumptions, and then define the pedestrian position estimation problem.

#### A. Assumptions

1) *Pedestrians:* We make the pedestrian's equipment minimum. We assume the following for each pedestrian.

- Each pedestrian is equipped with a beacon device.
- Beacon device emits a signal every  $t_b$  [s].
- A unique ID is assigned to each beacon device.
- Radio for sending beacon signals is based on IEEE 802.11 standard.

2) *Cars:* We assume the following for each car.

- Each car is equipped with a directional antenna capable of receiving beacon signals and estimating their directions.
- Each car is equipped with IEEE 802.11 based wireless LAN device, and capable of communication with other cars.
- Each car is equipped with a GPS receiver.
- Each car is equipped with a computer with a certain amount of storage and accurate clock.
- Road map is installed on the computer of each car.

3) *Inter Vehicle Communication:* We assume the following in communication between cars.

- Radio for beacon signals sent by pedestrians and packets exchanged between cars is based on IEEE 802.11.
- Time intervals for sending beacon signals and packets are  $t_b$  [s] and  $t_c$  [s], respectively.
- Each beacon signal propagates in the area with radius  $r_b$  [m] centered at its sender. All cars in the area receive the beacon signal as long as there is no radio interference.

- Each packet sent by a car propagates in the area with radius  $r_c$  [m]. All cars in the area receive the packet as long as there is no radio interference.

4) *Property of Directional Antenna*: We assume the following for directional antenna.

- When receiving a beacon signal, it can estimate the direction and distance to its sender pedestrian.
- Error in the measured direction follows normal distribution.
- Error in the measured distance follows normal distribution.

### B. Protocol for Pedestrian Position Estimation

We describe the behavior of each pedestrian and each car below.

(a) *Pedestrian's behavior*:

- 1) Construct a packet  $pkt_p(id, sn)$  with the pedestrian's beacon ID  $id$  and beacon sequence number  $sn$ .
- 2) Broadcast  $pkt_p(id, sn)$  to cars in the area of radius  $r_b$  centered at the pedestrian.
- 3) Increment the beacon sequence number  $sn$  by one.
- 4) Repeat 1) to 3) at time interval  $t_b$ .

(b) *Car's behavior*:

- 1) Wait until a packet is received.
- 2) If the received packet is the pedestrian's beacon  $pkt_p(id, sn)$ , take the following behavior.
  - a) Create a map of pedestrian's existence probabilities (described in Sect. IV) by estimating pedestrian's position from measured beacon signal and its position.
  - b) Construct a packet  $pkt_c(car\_pos, angle, d, id, sn)$  with its position  $car\_pos$ , measured angle  $angle$ , measured distance  $d$ , and pedestrian's ID and sequence number in the received packet.
  - c) Broadcast  $pkt_c(car\_pos, angle, d, id, sn)$  in the area with radius  $r_c$  centered at the car.
  - d) Repeat c) at time interval  $t_c$  until receiving another packet  $pkt_p(id, sn')$  with different sequence number from the same pedestrian.
- 3) If the received packet is other car's packet  $pkt_c(car'_pos, angle', d', id', sn')$ , take the following behavior.
  - a) Confirm beacon ID  $id'$  and sequence number  $sn'$ .
  - b) If the beacon packet  $pkt_p(id', sn')$  was already received, compute a map of pedestrian's existence probabilities for  $car'_pos$ ,  $angle'$ , and  $d'$ , and compose it with the existent map (composition algorithm is explained in Sect. IV).
  - c) Otherwise, create a map of pedestrians existence probabilities.

### C. Pedestrian Position Estimation Problem for Safety Navigation

We define the problem of estimating pedestrian's position using inter-vehicle communication as follows.

**Purpose**: Provide safety navigation to drivers by showing the position and moving direction of pedestrians.

**Input**: Position information of pedestrians measured by a car and brought from other cars through inter-vehicle communication

**Output**: Indicating positions of pedestrians in dangerous situations to drivers.

**Constraints**: By considering the time duration  $T$  [s] that car stops since its driver recognizes danger, the danger indication must be finished  $T$  [s] before the car hits the pedestrian.

## V. POSITION ESTIMATION ALGORITHM

In this section, we describe the algorithm to solve the problem defined in Sect. IV-C. The basic idea is as follows.

- 1) When a car receives a beacon packet from a pedestrian, it measures the angle and the distance to the pedestrian based on the signal received by the directional antenna, estimates the pedestrian's position from the angle and strength of the car's position, and computes the pedestrian's existence probability at each position around the estimated position, called *existence probability map*.
- 2) In order to make the existence probability map more accurately, we make cars exchange the probability maps computed by those cars, and compose the maps into a new map.

Below, we explain how we realize this idea.

### A. Input, Output, Constraint, and Objective of Problem

Below we will describe the details of input, output, constraint, and objective of the target problem.

**Input**: For each car  $c_i (i \in \{1, 2, \dots, n\})$ ,  $c_i$ 's position  $(x_i, y_i)$ , and the measured angle  $\theta_i$  and distance  $d_i$  to the pedestrian.

**Output**: Existence probability map of pedestrian  $w$ .

**Constraint**: The distance that a running car stops since its driver notices pedestrian in dangerous situation consists of *thinking distance* and *braking distance*, where the former is the distance that the car runs until the braking gets effective since the driver decides braking, and the latter is the distance that the car runs until it completely stops since the braking gets effective. In order to avoid traffic accidents of pedestrians, notification of estimated pedestrian position must be notified to a driver before the car goes into the area centered at the pedestrian with a radius of this distance.

The thinking distance and the braking distance are calculated by the following expressions (1) and (2).

$$d_{thinking} = t_{recognize} \cdot v \quad (1)$$

$$d_{braking} = \frac{(v/3.6)^2}{254 \cdot \mu} \quad (2)$$

Here,  $v$  is the car speed,  $\mu$  is the kinetic friction coefficient of the road, and  $t_{recognize}$  is the driver's response time, where  $t_{recognize}$  will typically be 2 seconds [11]. Thus, the distance

between a car and a pedestrian in danger is less than  $d_{limit}$  defined below.

$$d_{limit} = d_{braking} + d_{thinking} \quad (3)$$

**Objective:** Let  $w.pos(t)$  and  $c.pos(t)$  denote the positions of pedestrian  $w$  and car  $c$  at time  $t$ , respectively. We assume that the time when a car  $c$  in its radio range receives is the same as the time when the beacon packet is sent. For each car  $c$  and a pedestrian  $w$ , the purpose of our method is to complete indicating  $w$ 's position to  $c$ 's driver while the distance between  $c$  and  $w$  is larger than  $d_{limit}$ .

To solve the above problem, we present two algorithms: (i) algorithm for computing pedestrian existence probability map, and (ii) algorithm for composing a new map from multiple maps.

### B. Computing Pedestrian's Existence Probability Map

First, we will explain the model for the angle to the pedestrian measured by directional antenna. Let  $\theta_{measured}$  be the measured angle to the target pedestrian, where the base direction is the car's running direction, as shown in Fig. 2. Since there is a measurement error, the actual angle is somewhere around the measured angle  $\theta_{measured}$ . From assumption in Sect.IV-A, the probability  $f_{\Theta}(\theta)$  that the actual angle becomes  $\theta$  follows the normal distribution centered at  $\theta_{measured}$ , and denoted by the following equation.

$$f_{\Theta}(\theta) = \frac{1}{\sqrt{2\pi}\sigma_{\theta}} e^{-\frac{1}{2}\left(\frac{\theta - \theta_{measured}}{\sigma_{\theta}}\right)^2} \quad (4)$$

Here, the variance  $\sigma_{\theta}$  (e.g., 6 degrees) is decided depending on the property of the directional antennas equipped with cars.

Next, we will explain the model for measuring the distance to the pedestrian. Let  $d_{measured}$  denote the measured distance to the target pedestrian, which is computed by RSSI (Received Signal Strength Indicator) of the received beacon packet at the directional antenna (see Fig. 2). Due to measurement error, the actual distance is somewhere around the measured distance  $d_{measured}$ . From assumption in Sect.IV-A, the probability  $f_D(d)$  that the actual distance becomes  $d$  follows the normal distribution centered at  $d_{measured}$ , and denoted by the following equation.

$$f_D(d) = \frac{1}{\sqrt{2\pi}\sigma_d} e^{-\frac{1}{2}\left(\frac{d - d_{measured}}{\sigma_d}\right)^2} \quad (5)$$

We assume that the variance  $\sigma_d$  is given by  $\sigma_d = \alpha \times r_{rp}$ . Here,  $\alpha$  denote a constant number.

By using equations (4) and (5), we can calculate the probabilistic index that a pedestrian is at arbitrary position  $(x, y)$  in a map by the following equation.

$$p_{c_i}(x, y) = f_{\Theta}(\theta) \cdot f_D(d) \quad (6)$$

Here, denoting  $(x_i, y_i)$  to be the position of car  $c_i$ , and  $\theta$  and  $d$  are calculated by the following equations.

$$\theta = \tan^{-1}\left(\frac{|y - y_i|}{|x - x_i|}\right), \quad -\frac{\pi}{2} \leq \theta \leq \frac{\pi}{2} \quad (7)$$

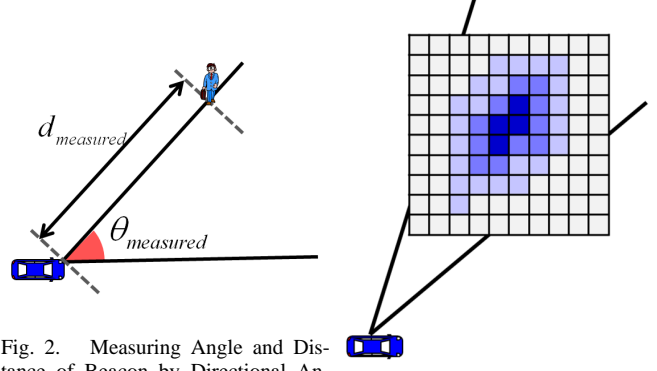


Fig. 2. Measuring Angle and Distance of Beacon by Directional Antenna

Fig. 3. Pedestrian's Existence Probability Map

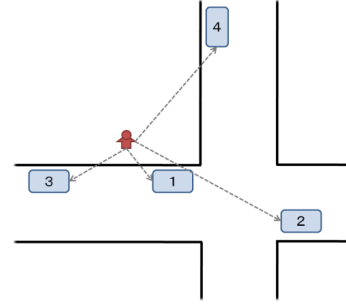


Fig. 4. Example of composing multiple probability index

$$d = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (8)$$

Below, we consider the allowable error in pedestrian position estimation. In general, pedestrian's moving speed is said to be 4Km/hour (i.e., 1m/sec). In the proposed method, in order to reduce computation time, we divide the target space in a road map into grids with 1 meter sides as shown in Fig. 3, give each grid probabilistic index calculated for the central point  $(x, y)$  of the grid by equation (6).

We use Bayes' theorem to calculate  $f_{\Theta}(\theta)$  and  $f_D(d)$ .

### C. Composing New Probability Map from Multiple Maps

Now, we will explain how to improve the estimation accuracy of position by composing probability maps obtained by multiple cars.

In order to compose multiple probability index, the measurement data have to satisfy the following conditions.

- All cars receive the same beacon with same ID transmitted at the same time.

The probability index  $\{p_{c_1}, p_{c_2}, \dots, p_{c_m}\}$  derived from the received beacon which satisfies the above condition, we calculate the new probability index by Bayes theorem.

## VI. SIMULATION EXPERIMENT AND EVALUATION

In this section, we describe the results of computer simulation for evaluating how accurately the proposed system with inter-vehicle communication can estimate the pedestrian's locations before the limit of time for stopping a car. In this

evaluation, we have used QualNet Simulator [12] to simulate wireless communication.

### A. Experimental Parameters

The target area is a large intersection located at Shijo-Kawaramachi, which is in the central Kyoto, shown in Fig. 8, 9, and 10. The size of this area is 142[m]  $\times$  142[m]. This intersection has a set of traffic signals, the signals for east-west direction is set to green, and the signals for north-south direction is red. We varied the number of cars which go through the intersection in the east-west direction among 2, 4, 6 and 8, and the number in the north-south direction among 2, 4, 6, 8 and 10. The moving speed of all cars on the road with green signal are 50[km/h], and all cars keep 10m as the distance from the preceding car. The drivers' response time  $t_{recognize}$  from recognizing danger to pedal the brakes is assumed to be 2 seconds. We placed 12 pedestrians in this area. The road condition in the area is dry and its coefficient  $\mu$  of friction is 0.7. In this case,  $d_{limit}$  becomes 22 meters. Pedestrians' devices for transmitting beacon and the inter-vehicle communication use IEEE 802.11b as the physical layer protocol. The radio propagation range is 100 meters. The interval of broadcasting pedestrians' beacon  $t_b$  is 0.2 seconds and the interval of broadcasting data from each car  $t_c$  is also 0.2 seconds. The size of a pedestrian's beacon is 100 bytes, which contains a Beacon ID and a Packet Sequence Number. A location of each car is represented as coordinates  $(x, y)$  and the length of each coordinate value is 64 bits. The size of data measured by a car is 150 bytes. In order to reproduce multipath fading, Rayleigh Fading model is used as the radio propagation model. Irregular Terrain Model is used as the path loss model and the normal distribution is used to reproduce shadowing in this simulation.

### B. Evaluation Items

The items for evaluation are shown below.

- 1) **Packet Loss Rate:** In order to evaluate how many packets can be received until the car reaches within the distance of  $d_{limit}$  from a pedestrian, we measured the number of beacons successfully received by a car when this car is going through the intersection from the right side.
  - a) The ratio of successfully received beacons
  - b) The number of successfully received beacons
- 2) **Estimation Accuracy of Pedestrian's Location:** In order to evaluate how the accuracy of estimation changes as the number of cars exchanging information changes, we measured the radius of the smallest circle which contains all cells of the grid in which the existence probability of pedestrian exceeds 90%. We varied the number of cars exchanging information with the front car from 0 to 8. The variance  $\sigma_\theta$  of the normal distribution for the error of angle of arrival is set to 6[deg], and the variance  $\sigma_d$  for the error of distance is varied among 10[m], 20[m] and 30[m].

### C. Experimental Result

The results of the simulation for the evaluation 1-a is shown in Fig. 5. This figure shows the ratio of the packet which cannot be received until the car reaches within the distance of  $d_{limit}$ . This results show that the ratio of packet loss does not increase as the number of cars in the area increases. The packet loss rate stays around 4% even when there are 18 cars in the area. Figure 6 is the result of the simulation for the evaluation 1-b, which is the number of packets received until the car reaches within the distance of  $d_{limit}$ . For all conditions, the car is able to receive more than 14 packets until the deadline, which is sufficient for estimating the position of the pedestrian.

Figure 7 shows the radius of the smallest circle which contains all cells of the grid in which the existence probability of pedestrian exceeds 90%, while the number of cars exchanging information is changed from 0 to 8. From this figure, we can see that when  $\sigma_d=10$ [m], the radius is 18.33[m] when there is only one car, but the radius becomes 3.74[m] if there are 8 cars. Thus, the accuracy of estimation improves as the number of cars increases. We can see the same result when  $\sigma_d=20$ [deg] and 30[deg]. Fig. 8, 9 and 10 show the results of position estimation when there are 2 cars in vertical direction and 2 cars in horizontal direction. In these simulations, the coordinates of the pedestrian is  $(48, 76)$ [m]. These results show that on any conditions, the accuracy of estimation is improved as the number of cars exchanging information increases.

## VII. CONCLUSION

In this paper, we presented a method for pedestrian position estimation using inter-vehicle communication. In the proposed method, we used a pedestrian existence probability model in order to consider a measurement error, and cars exchange pedestrian existence probabilities using inter-vehicle communication in order to detect pedestrians with high accuracy. We have implemented the proposed system on the network simulator QualNet and confirmed that cars detect a pedestrian until a distance between a driving car and a pedestrian gets smaller than car's stopping distance.

As the future work, we will consider the way for evaluating each pedestrian's accident risk for each driver and filtering out low accident risk pedestrians so that each driver can focus on higher accident risk pedestrians. We will also consider the way that cars detect a series of pedestrian's position for a time interval in order to estimate the pedestrian's moving direction. In this paper, we have implemented the proposed system at a blind intersection. We will implement the proposed system at a road that a car often collide with a pedestrian who run out into the street.

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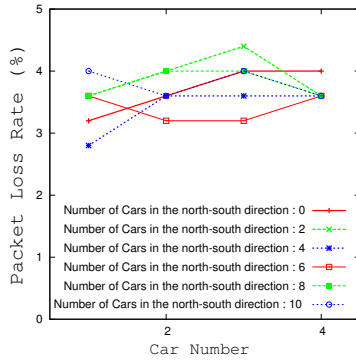


Fig. 5. Transmitted Packet Loss Rate among Multiple Cars

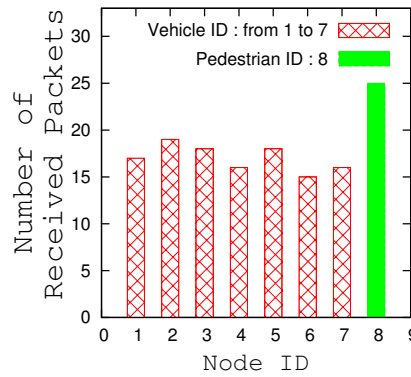


Fig. 6. Number of Received Packets from 8 Neighboring Cars

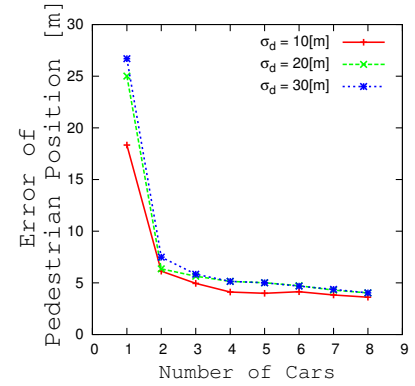


Fig. 7. Change in Estimation Accuracy of Pedestrian's Location by Multiple Cars

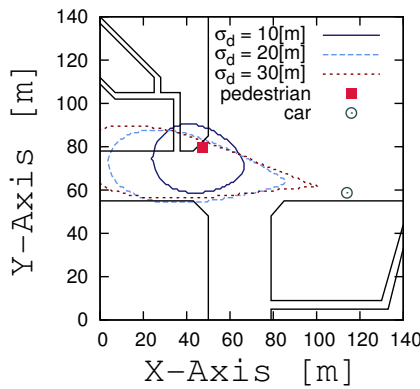


Fig. 8. Probability index of Pedestrian's Location measured by 1 Car

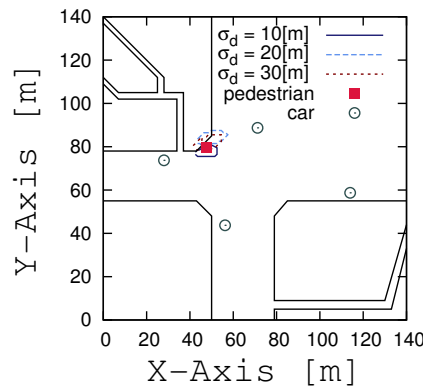


Fig. 9. Integrated Probability index of Pedestrian's Location measured by 4 Cars

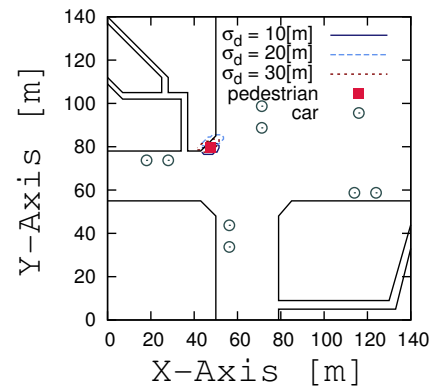


Fig. 10. Integrated Probability index of Pedestrian's Location measured by 8 Cars

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