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日本木屐：利用足跡追蹤位置系統

The GETA Sandals: A Footprint Location Tracking System

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Abstract

This paper presents the design, implementation, and evaluation of a footprint-based indoor location system on traditional Japanese GETA sandals. Our footprint location system can significantly reduce the amount of infrastructure required in the deployed environment. In its simplest form, a user simply has to put on the GETA sandals to track his/her locations without any setup or calibration efforts. This makes our footprint method easy for everywhere de-ployment. The footprint location system is based on the dead-reckoning method. It works by measuring and tracking the displacement vectors along a trial of footprints (each displacement vector is formed by drawing a line between each pair of footprints). The position of a user can be calculated by summing up the current and all previous displacement vectors. Additional benefits of the foot-print based method are that it does not have problems found in existing indoor location systems, such as obstacles, multi-path effects, signal noises, signal in-terferences, and dead spots. However, the footprint based method has a problem of accumulative error over distance traveled. To address this issue, it is com-bined with a light RFID infrastructure to correct its positioning error over some long distance traveled.

Chapter 1

Introduction

Physical locations of people and objects have been one of the most widely used context information in context-aware applications. To enable such location-aware applications in the indoor environment, many indoor location systems have been proposed in the past decade, such as Active Badge [12], Active Bat [6], Cricket [9], smart floor [11], RADAR [10], and Ekahau [1]. However, we have seen very limited market success of these indoor location systems outside of academic and industrial research labs. We believe that the main obstacle that prevents their widespread adoption is that they require certain level of system infrastructural support (including hardware, installation, calibration, maintenance, etc.) inside the deployed environments. Significantly reducing the needed system infrastructure serves as our main motivation to design and prototype a new footprint location system on traditional Japanese GETA (pronounced ”gue-ta”) sandals. This footprint location system can compute a user’s physical location solely by using sensors installed on the GETA sandals. To enable location tracking, a user simply has to wear the GETA sandals with no extra user setup and calibration effort. This system works by attaching location sensors, including two ultrasonic-infrared-combo readers and one ultrasonic-infrared-combo transmitter, on the GETA sandals. The basic idea can be described by looking at a person walking from location A to location B on a beach. He/she will leave a trial of footprints. To track a person's physical location, the system continuously measures a displacement vector formed between two advancing footprints (advancing in the temporal sense). To track a user's current location relative to a starting point, the system simply sums up all the previous footprint displacement vectors leading to his/her current footprint location. This idea is similar to the so-called (deduced) dead-reckoning navigation dated back to the medieval time when the sailor/navigator would locate himself/herself by measuring the course and distance sailed from a starting point. In our system, this dead reckoning idea is adapted in tracking human footprints. We believe that having a wearable location tracker is an important advantage in our footprint location system over infrastructure-based indoor location systems. Users simply need to wear our GETA-like shoes, and our location system can work anywhere they want to go. In addition to the benefit of low infrastructure cost, the footprint location system does not have problems commonly found in existing indoor location systems. For example, existing wireless based solutions (e.g., using radio, ultrasonic, or infrared) can experience poor position accuracy when encountering obstacles between transmitters and receivers, multi-path effects, signal noises, signal interferences, and dead spots. On the other hand, our footprint location system avoids almost all of these problems. The reason is that the location sensors (ultrasonic-infrared transmitters and readers) in our footprint method only need to cover a small sensing range, which is the short distance between two sandals in a maximum length of a walking step ($<$ 1.5 meters).

Assume walking on a relatively smooth surface, the footprint location sensors are unlikely to encounter any obstacles or experience multi-path effects, signal noises, and signal interferences over this small sensing range. This is in contrast to existing wireless (radio, ultrasonic, or infrared) based location systems where the sensing range must be large enough to cover the distance between fixed location sensors in the environment and a mobile location sensor on a user. This short sensing range in our footprint method also brings two additional advantages:

1. location sensors can significantly reduce its power consumption due to short sensing range,
2. location sensors (ultrasonic-infrared) have high accuracy under such short sensing range (e.g., 0.2 mm in static setting).

There is one important shortcoming in our footprint location system called the error accumulation problem. It is inevitable that a small amount of error is introduced each time we take measurements to calculate a displacement vector. Consider a user has walked n steps away from a starting point. His/her current location is calculated as a sum of these n displacement vectors. This means that the current location error is also the sum of all errors from these n previous displacement vectors. In other words, the error in the current footprint measurement will be a percentage of the total distance traveled. To address this error accumulation problem, we utilize a small number of passive RFID tags with known location coordinates in the environment. A small RFID reader is also placed under a GETA sandal to read these RFID tags. When a user walks on top of a location-aware RFID tag, the known location coordinate of that RFID tag is used instead of the calculated footprint location. Encountering a RFID tag has the same effect as resetting the accumulated error to zero. Although these location-aware RFID tags are considered system infrastructure, they constitute very light infrastructure because

1. RFID tags are relatively inexpensive in cost ($<$ \$1 each)and easy to install,
2. only a very small number of RFID tags are needed.

Based on our measurements in Section 4, the average error per footstep is only about 4.6mm. If we want to limit the average error to 46cm, we only need to install enough RFID tags in the environment such that a user is likely to walk over a RFID tag approximately every 100 steps. There are several pervious systems that are also based on incremental motion and dead reckoning. Lee et al [7] proposed a method to estimate the user's current loca-tion by recognizing a sequence of incremental motions (e.g., 2 steps north followed by 40 steps east, etc.) from wearable sensors such as accelerometers, digital compass, etc. Lee's proposed method differs from our footprint tracking system in that it can only recognize a few selected locations (e.g., bathroom, toilet, etc.) rather than track location coordinates. Point research [5] provides a vehicle self-tracking system that provides high location accuracy by combining the dead-reckoning method (wheel motions) and GPS. The solution from Point research differs from our method which is based on footprint tracking in normal human walking motion rather than mechanical wheel movements. At the time of this paper writing, we have gone through three design-and-evaluation iterations. Rather than presenting only the last (3rd) design and evaluation, we think that readers may also be interested to know these intermediate designs as well as mistakes we made on them. This thesis will be organized as follows. In Sections 2 to 4, we describe our three design-and-evaluation iterations, including performance evaluations and discussions about design mistakes. Section 5 draws our summary and future work.

Chapter 2

Related Work

At present, there are numerous papers using many different kinds of technology and approach for realizing an indoor location tracking system. Since the purpose of this project is for easy-deployment in home and office environment we focused the following three criteria to evaluate each different related approach. Those are accuracy, cost, and user wear-ability.

1. Accuracy

   It means that when we implement our proposed method, how accurate our estimated location is compared to the true location. For example, in some project, if the estimated location is (2.0, 4.0) and real location is (5.0, 8.0) the inaccuracy rate for this is 5.0.

2. Cost

   To consider cost there are three factors that we need to consider. First, it is time cost for the infrastructure and calibration. This indicates that when we implement our proposed approach, we need to consider if it is necessary to make some change in the environment.

For example, we need to set up some devices in the ceiling or high wall and so on. The preparation for such an environment need a great deal of time cost. Second, cost for device or hardware. When we implement we need to rely on some existing device for calculation of the location and if necessary need some extra device which will help calculate their positioning. Third, cost for the space. When we use the existing device we need the space for those devices for realizing an indoor location environment. Fourth, cost of maintenance. For example, if it's necessary to change battery for the technology for every certain period of time, this is surely the cost of maintenance.

3. User wear-ability

   In existing proposed indoor location tracking system, the user is required to wear certain level of devices on their body or carry some devices. If the user need to wear heavy device he or she will feel very uncomfortable to use in home and office environment. Therefore, this is also important factor to be considered for the evaluation of each approach. The best approach is that even though a user carries some device the user will not notice that he or she is carrying some device wherever they go.

From here I described the following related work by considering the three criteia mentioned above.

Active Badge [12]

A user wears a badge in the office environment which transmits signals including information of his or her location to a central system using infrared sensors. The badge size is about 55 x 55 x 77 mm and weighs 40g. Therefore, it is very portable for the user to carry anywhere around the office environment. The disadvantage is that sensors need to be set up on high walls or ceiling in the office to make the badge detected. Signaling range is 6 m and the signals do not penetrate the wall unlike radio signals. It also works poorly in the presence of direct sunlight. Furthermore, sensors also need to place on the entrances and exits of corridor and other necessary areas. Therefore, it has significant infrastructure cost.

Active Bat [6]

A user is required to carry a small sensor tag called bat. The bat consists of a radio transceiver, controlling logic and an ultrasonic transmitter and its size is 5 cm x 3 cm x 2 cm , weighing only 35 g. Their indoor location system is that a base station is periodically transmits signals to the bat which transmits the pulse of ultrasound to the receiver which installed on the ceiling of a room. Using triangulation the system calculates the distance of the user. The accuracy is within 9 cm with the 95 percent of the reading. In their experiment they use two base stations and 100 receivers in the two rooms of approximately 280 m^3. Thus, it needs great deal of infrastructure cost in the beginning. The battery is also periodically needed to change although it does not need to do so often. Moreover, a great deal of system infrastructure is also needed to set up to realize such an environment.

Cricket location systems [9]

Cricket uses beacons which installed on the ceiling or high on the wall to provide information of a user's location to listeners through a combination of Radio Frequency and ultrasound. The listener is attached to every mobile and static node to obtain such information. Each beacon and listener only cost US $10. Since their location granularity is 4 x 4 feet, they place a beacon every 4 x 4 feet, which is not very accurate compared with the active bat even though the approach is very similar. Like the active bat the disadvantage is that they need to install many beacon on the ceiling and high on wall and since they have typical ultrasonic problem such as multi-path effect and obstruction problems, they also need a great deal of infrastructure cost to make sure this system works well.

RADAR [10]

RADAR uses a Radio Frequency to locate the user's location inside the building. They put three base stations in the room of 43.5 m by 22.5 m. The user carries mobile host to be tracked. Each base station gathered signal strength information together with a synchronized timestamp during the off-line phase and the real-time phase and then determines the user's coordinates. Here, they need a significant calibration effort. Their location accuracy is within a few meters of the user's actual coordinates. In order to make such an environment they builds floor layout information and also computed obstructs such as walls which interfere to collect signal strength information. Thus, it also need significant infrastructure and calibration effort and not easy to deploy.

Ekahau [1]

WiFi based location systems require an existing WiFi network in the deployed environment. For example, the Ekahau location system recommends a WiFi client to be able to receive signals from 3-4 WiFi access points in order to attain the specified location accuracy of 3 meters. This high density of access points is unlikely in our everyday home and small office environments. In addition, most WiFi based location systems require users' calibration efforts to construct a radio map by taking measurements of WiFi signal strength at various points in the environment. This forms another barrier for users.

Smart floor [11]

Smart floor can track the location of a user by using pressure or presence sensors underneath the floor tiles to detect the user's gait. The advantage is that a user does not need to wear or carry any devices and can identify people with 93 percent of accuray. The drawback is that this infrastructure cost is expensive because it requires custom-made floor tiles and flooring re-construction.

Easyliving [14]

They use two sets of color stereo camera for tracking people in a room. So, they use computer vision to determine the location and identity of people in the room. The system can measure location approximately 10 cm on the ground plane and it can track multiple people simultaneously. However, they need to make a great deal of infrastructure and calibration effort to realize such a smart environment.

DMLP system [8]

They use extremely low frequency magnetic fields to measure absolute position and attitude through a mobile robot. This robot navigation indoor positioning system could obtain a few inches and degrees of accuracy even in the midst of line of sight obstructions. Inexpensive beacons are distributed throughout the building and they create low magnetic fields. A mobile sensor unit collect samples of the local magnetic field and distinguishes each field from different beacon. Then it can solves for its position and attitude. Any number of sensor units can be used at the same time in the operation. However, one likely location for setting up the beacons is a space between a ceiling and the floor of the next higher level and several hundres of them could be needed thruoughtout a large building or warehouse. Therefore, these condition will be required tremendous infrastructure effort.

Location and Proximity Sensing for the Blind User [13]

This is a navigation system to help the blind or visually impaired people have more comfortable indoor and outdoor life by using passive RFID technology. For the indoor navigation infrastructure, they use passive RFID grid. It means that RFID tags that contain the information of their location and their surroundings can be integrated with carpet on the floor. If we need an accuracy of one foot it is required a cost of 10 x 12 x $ 1.00 for a room size of 10 x 12. For the area such as hallways, stairs, so on, RFID tags are needed to install on the edge of the path. For the outdoor navigation infrastructure the RFID tags are placed on the edge of the sidewalk and the users simply need to walk over the tags with RFID reader. The RFID reader can be integrated into a cane or attached to a pair of shoe or handheld device such as PDA. The passive RFID is low in power, Thus it is impossible to reader the tags with the walking speed of sighted people. Since their application scenario is for blind people they expect the blind walk slowly enough to detect RFID tags.

Virtual Leading Blocks for the Deaf-Blind [15]

This is also the navigation system to help the deaf-blind in both indoor and outdoor environment. They use active RFID technology for indoor environment in order to complement GPS for outdoor environment. A user wears motion sensor to know the orientation, backpack which contains wearable computer and two RFID readers, and Finger-Braille interface with wristwatch computer. Their application scenario is based on the water splitting using either verbal or non-verbal instruction to split a watermelon. The wearable computer sends verbal and nonverbal information to the user through a Finger-Braille interface. In their experiment, 1,394 active RFID tags are installed on the floor with 1.2 meter spacing. The size of floor is approximately 1,700 m^2. Like the passive RFID method a user's position can be obtained by referring the information of the number of detected RFID tags. However, their calculation method is different from above that using two RFID readers the position is calculated by averaging all the position of the detected tags.

Chapter 3

Initial design: Design Version I

The human walking motion can be modeled by stance-phase kinematics shown in Fig. 3.1. A forwarding walking motion is consisted of a sequence of three stances - heel-strike, mid-stance, and toe-off. In the heel-strike stance, the body weight pushes down from the upper body to the lower body, resulting in both feet in firm contact with the ground. This generates a footprint on the ground. In the mid-stance, the body raises one (left) foot forward and above the ground. In the toe-off stance, the body weight again pushes down on the forwarded (left) foot, again resulting in both feet in contact with the ground. This creates another footprint on the ground. The basic idea behind our footprint location tracking system is to

1. detect heel-strike and toe-off stances,

2. take measurement of two feet's displacement vector v_d (i.e., the footprint vector) on the ground.

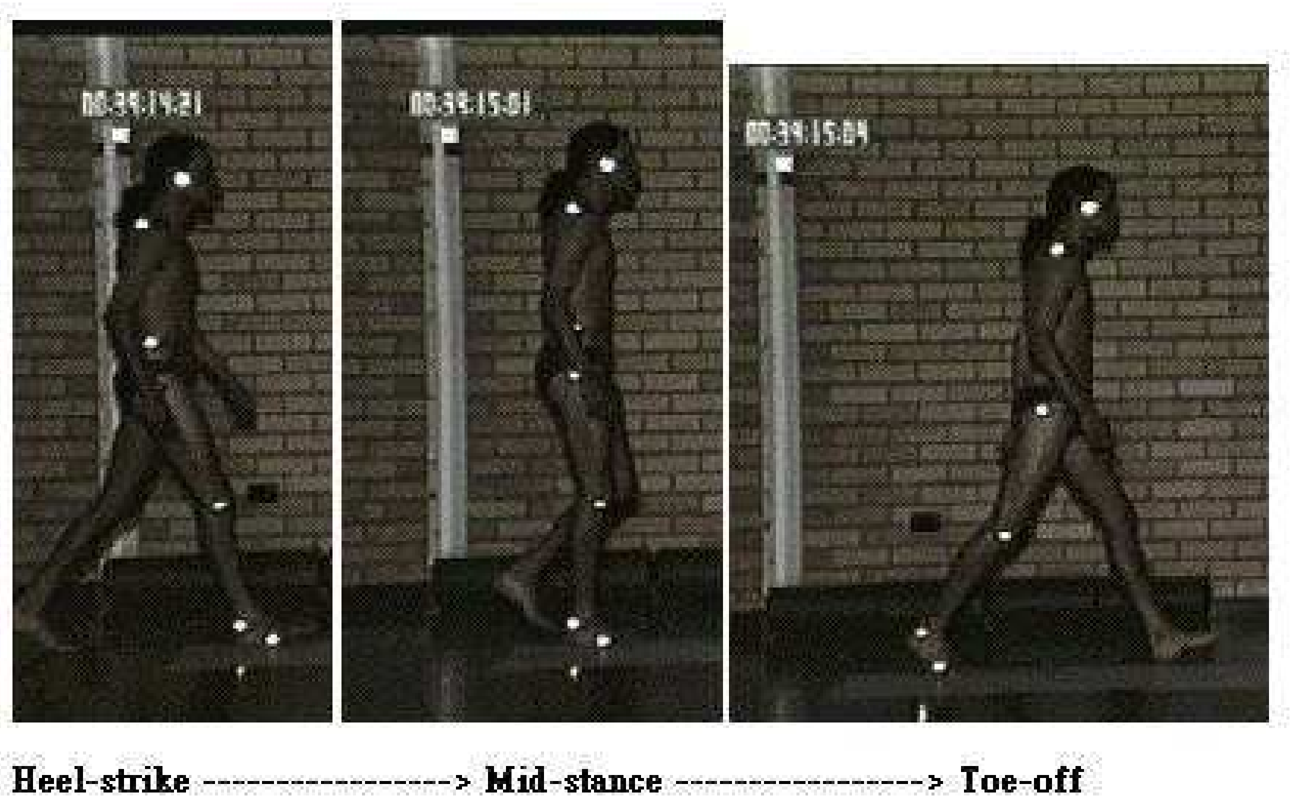


Figure 3.1: Three stances in a normal human walking motion

As shown in Fig. 3.2 given a starting point in a location tracking region (x_start, y_start), e.g., the entrance of home or a building, we can compute the current position of a user, who has walked n number of steps away from the starting point, by summing up all displacement vectors $\sum v_{di}$, for $i = 1 \ldots n$, corresponding to these n footsteps.

3.1 Footprint Positioning Algorithm

To measure the displacement vector v_d for each footprint, we place two ultrasonic-infrared-combo receivers on the left sandal and two ultrasonic-infrared-combo transmitters on right sandal shown in Fig. 3.3. The components for ultrasonic-infrared transmitters and receivers are obtained by disassembling the NAVInote's [3] electronic pen and base unit. In order to make both the receivers and transmitters face directly toward each other during normal walking motion , they are placed on the inner sides of the sandals. The prototype of the GETA sandals is shown in Fig. 4.2. Through NAVInote APIs, we obtain the (x, y) coordinates of these two transmitters located on the right sandal. Denote them as (x_{t1}, y_{t1}) and (x_{t2}, y_{t2}) as shown in Fig. 3.3. Note that the ultrasonic-infrared-combo technology can achieve very fine position accuracy and resolution at the short sensing range between two sandals. Under static setting, the measured average positioning error is $<$ 0.2mm and the resolution is $<$ 0.2mm.

The coordinates of these two transmitters are measured relative to the local coordinate system of the left sandal, where the origin of this local coordinate system is at the heel position and the y-axis forms a straight line from the heel to the toes. Since moving left foot also changes the local coordinate system, it is necessary to re-orientate the displacement vector from its local coordinate system to a global coordinate system.

The global coordinate system is set to be the coordinate of the starting point. To perform this orientation translation, we need to compute the orientation angle θ of local coordinate system relative to the global coordinate system. Denote the current step as the i-th left footstep. The orientation angle θ can be calculated as $\sum \theta_i$, where θ_i is the rotational angle between the i-th left footstep's coordinate system and the (i-1)-th left footstep's coordinate system. This means that to

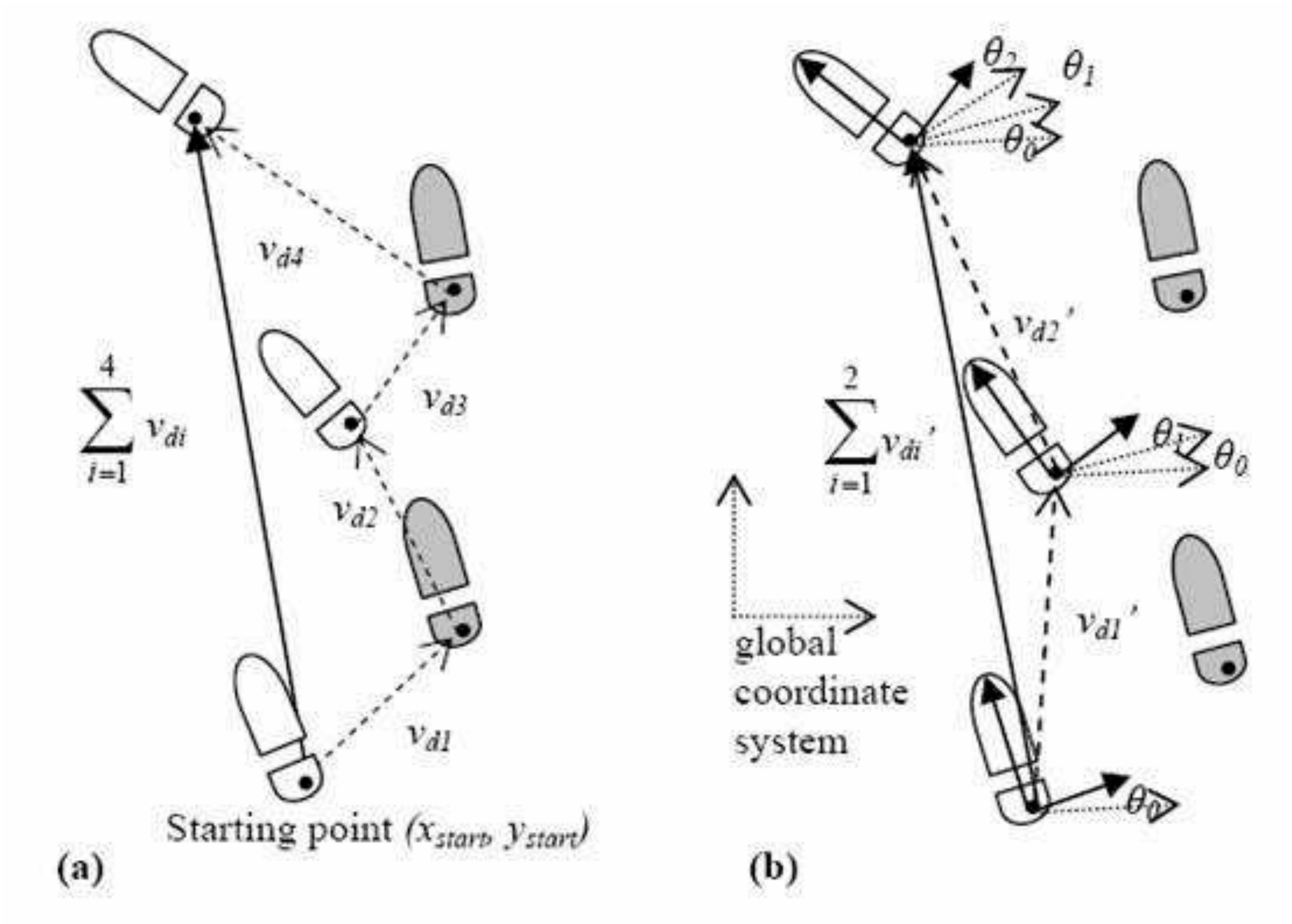


Figure 3.2: The user has walked four footsteps 1-4. Fig. 3.2(2a) shows these displacement vectors (v_{di}) corresponds to these displacement vectors. Fig. 3.2(2b) shows θ_i as the rotational angel between the current local coordinate system and the previous local coordinate system in the previous footstep.

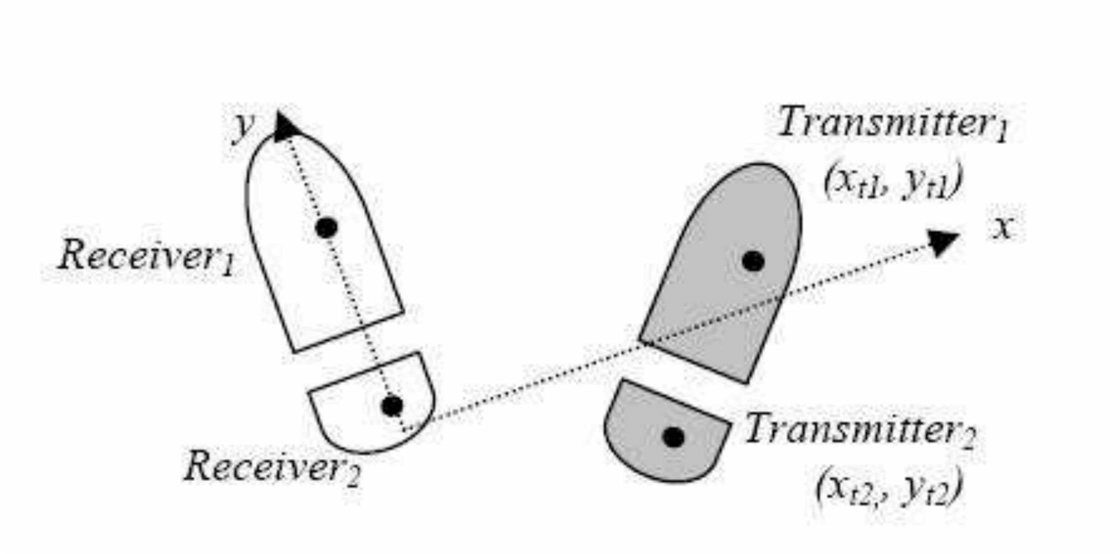


Figure 3.3: It shows the locations of ultrasonic-infrared receivers and transmitters on the sandals. The coordinates of the transmitters on the right sandal is relative to the local coordinate system on the left sandal.

compute the orientation angle θ, we need to compute θ_i for each new left footstep as illustrated in Fig. 3.2(2b). Fig. 3.4 shows (x_{t1}, y_{t1}) and (x_{t2}, y_{t2}) as the recorded coordinates of two transmitters on the right foot before moving the left foot, and ($x_{t1'}$, $y_{t1'}$) and ($x_{t2'}$, $y_{t2'}$) as their recorded coordinates after moving the left foot. As the left foot moves, the coordinate system on the left foot rotates θ_i and then translates into (dx, dy). This gives us the following four sets of equations, which are sufficient to solve for three unknowns: θ_i and (dx, dy).

$$\begin{pmatrix} cos\theta_i & sin\theta_i \\ -sin\theta_i & cos\theta_i \end{pmatrix} \begin{pmatrix} x_{t1} \\ y_{t1} \end{pmatrix} - \begin{pmatrix} dx \\ dy \end{pmatrix} = \begin{pmatrix} x_{t1'} \\ y_{t1'} \end{pmatrix}$$

$$\begin{pmatrix} cos\theta_i & sin\theta_i \\ -sin\theta_i & cos\theta_i \end{pmatrix} \begin{pmatrix} x_{t2} \\ y_{t2} \end{pmatrix} - \begin{pmatrix} dx \\ dy \end{pmatrix} = \begin{pmatrix} x_{t2'} \\ y_{t2'} \end{pmatrix}$$

We can then compute vd using summed θ, dx, and dy.

$$\begin{pmatrix} cos\theta_i & sin\theta_i \\ -sin\theta_i & cos\theta_i \end{pmatrix} \begin{pmatrix} dx \\ dy \end{pmatrix} = V_d$$

Some readers might wonder why we use two transmitters instead of one transmitter. The reason is that one transmitter only gives two equations, which are insufficient to solve three unknowns. With the additional transmitter, it can give two additional equa-tions needed to solve three unknowns. Prior to the above-mentioned geometry calculation, we need to detect the heel-strike and toe-off stances to measure (x_{t1}, y_{t1}) and (x_{t2}, y_{t2}). We call these two stances the steady state because when both feet are in contact with the ground, the measured coordinates on two transmitters are stable (do not change much) for some small period of time. When we detect the steady state, we record the coordinates of two transmitters and then calculate the displacement vector. Assume that the user moves the right foot and the left foot in an interleaving manner. We can track the position of the left foot by first computing two displacement vectors from left footprint to the right footprint and right footprint back to the left footprint.

3.2 Performance Evaluation

We have evaluated the performance of our initial design. The results have shown poor positioning accuracy. The main cause of poor accuracy is due to the interference of the signals from the two transmitters. Since the receivers can not distinguish two distinct signals from two transmitters, it can calculate incorrect coordinates on two transmitters. This leads to miss-detection of the steady

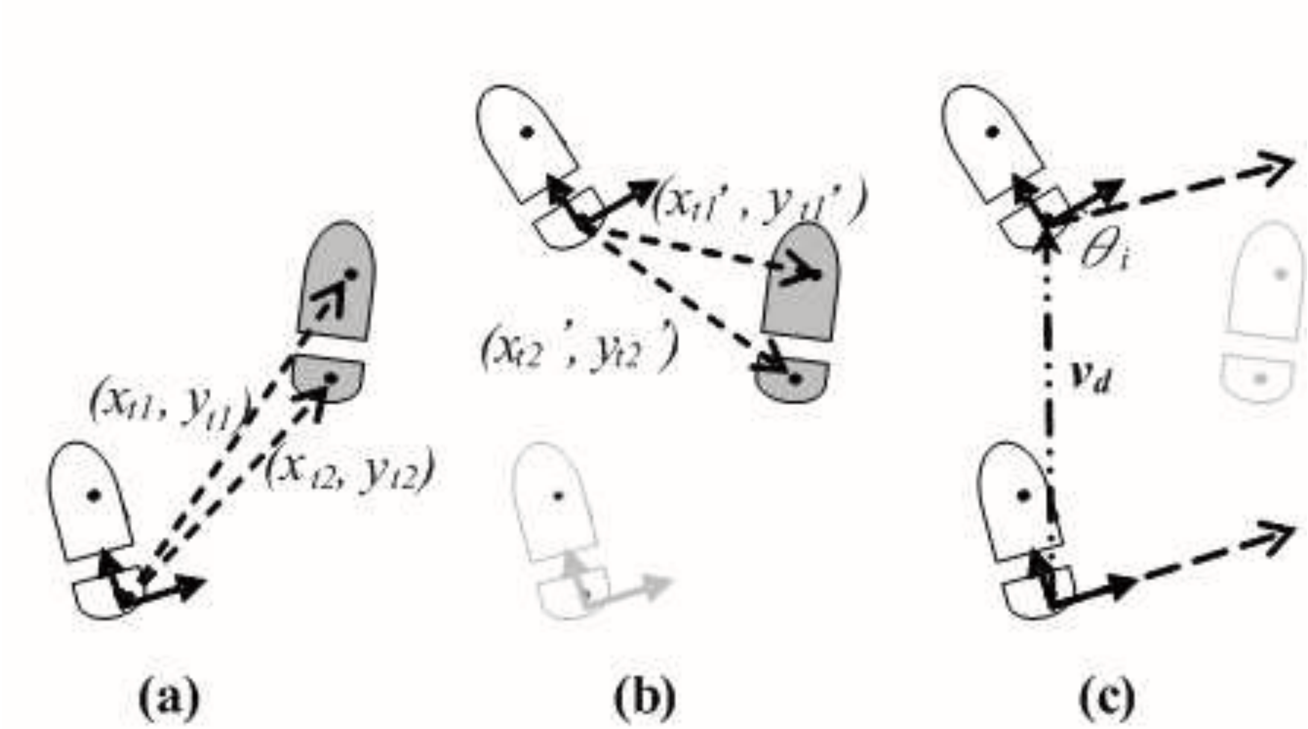


Figure 3.4: Before moving the left foot, the coordinates of the transmitters on the right sandal, $(x_{t1},\, y_{t1})$ and $(x_{t2},\, y_{t2})$, are recorded as shown in (a). After walking the left foot, $(x_{t1},\, y_{t1})$ and $(x_{t2},\, y_{t2})$ are recorded as shown in (b). To calculate vd, we have to consider the rotation angel θ_i, translate (dx, dy) to the coordinate system of the left foot, and then transform them into the global coordinate system to get the displacement vector v_d, as shown in (c).

state and incorrect calculation on the displacement vectors. Although we tried to filter out these incorrect coordinates, our results still showed high 49% rate of steady state miss-detections. When a miss-detection occurs, dx, dy, θ, and displacement vector will also be calculated incorrectly. This leads to rapid error accumulation. Note that even a small error in the rotation angle θ, which is used to reorient the displacement vector, can significantly reduce the position accuracy.

An additional problem is that we have not found a working method to distinguish if a person is moving forward or backward and which (left or right) foot is moving. This problem can be explained as follows. Consider the 1st case that a person is moving forward: if the right foot is moving forward, the x-coordinates of both transmitters will increase; on the other hand, if the left foot is moving forward, the x-coordinates of both transmitters will decrease. Consider the 2nd case that a person is moving backward, the situation is reverse, i.e., the x-coordinate will decrease(increase) when right(left) foot is moving backward. Given increasing x-coordinates on transmitters, it can be either right foot moving forward or the left foot moving backward. As a result, it is impossible to distinguish if a person is moving forward/background and left/right (foot movement).

3.3 Revised design: Design Version II

Design II tries to fix the following three problems from design I:

1. interferences from two transmitters,
2. incorrect detections of heel-strike and toe-off stances,
3. indetermination of forward/backward and left/right movements.

Design II solves these problems by incorporating additional sensors into the GETA sandals. To accurately detect the heel-strike and toe-off stances, we have added two pressure sensors at the bottom of both sandals to sense when both feet are in contact with the ground. These pressure sensors are also used to distinguish the forward/backward and left/right movements. To eliminate interferences from two transmitters, we remove one transmitter from the right sandal and incorporated an orientation sensor by InterSense InterTrax2[2] on the front of left sandal. Fig. 4.2 shows the GETA sandal prototype of the revised design (version II).

3.4 Revised Footprint Positioning Algorithm

Since the orientation sensor can provide θ value for the global coordinate system, it removes one unknown in our calculation. This leads to a simpler algorithm than in version I. By measuring (x_t, y_t) and θ at the time of the heal-strike and toe-off stances, the displacement vector in the current footstep can be calculated by performing a simple rotational transformation. The displacement vector to the starting point is the sum of all the displacement vectors corresponding to the all previous footsteps.

3.5 Performance Evaluation

Fig. 3.5 shows the measured positioning error over different traveling distances and walking speeds. It has shown that two problems in design I have been addressed. The positioning accuracy is very good at short walking distances: the average error after walking a little more than 5m is only 0.36m, or approximately 6.8%. It also shows that our new design can accurately detect the heel-strike and toe-off stands, and then take measurements to compute the displacement vector. It can be seen that the error increases only slightly with increasing walking speed. However, we can clearly observe the problem of error accumulation in our footprint-only method, as the positioning error increases superlinearly with increasing walking distance. The error is contributed from two main sources:

1. the displacement error vector from the ultrasonic-infrared-combo device,
2. the orientation error from the orientation sensor.

The displacement error is relatively small and stable due to the high accuracy in the ultrasonic-infrared-combo device. However, the displacement error is accumulative in future location calculation, so the error distance follows a linear growth pattern. Note that orientation error is more destructive than displacement error, i.e., even a one-time orientation error can make the positioning error grow linearly over walking distance. This can be explained by looking at Fig. 4.1. After the one-time orientation error of cerror occurs, the calculated path will forever deviate from the real path, leading to linear grow in error displacement. In addition, we have found that our orientation sensor becomes inaccurate after rotating over 90 degrees. In order to get more accurate rotation angle θ, we reset the orientation sensor after each left step, and then sum up each rotation θ_i to get the orientation θ. Due to this extra calculation, the orientation error of θ_i also becomes accumulative.

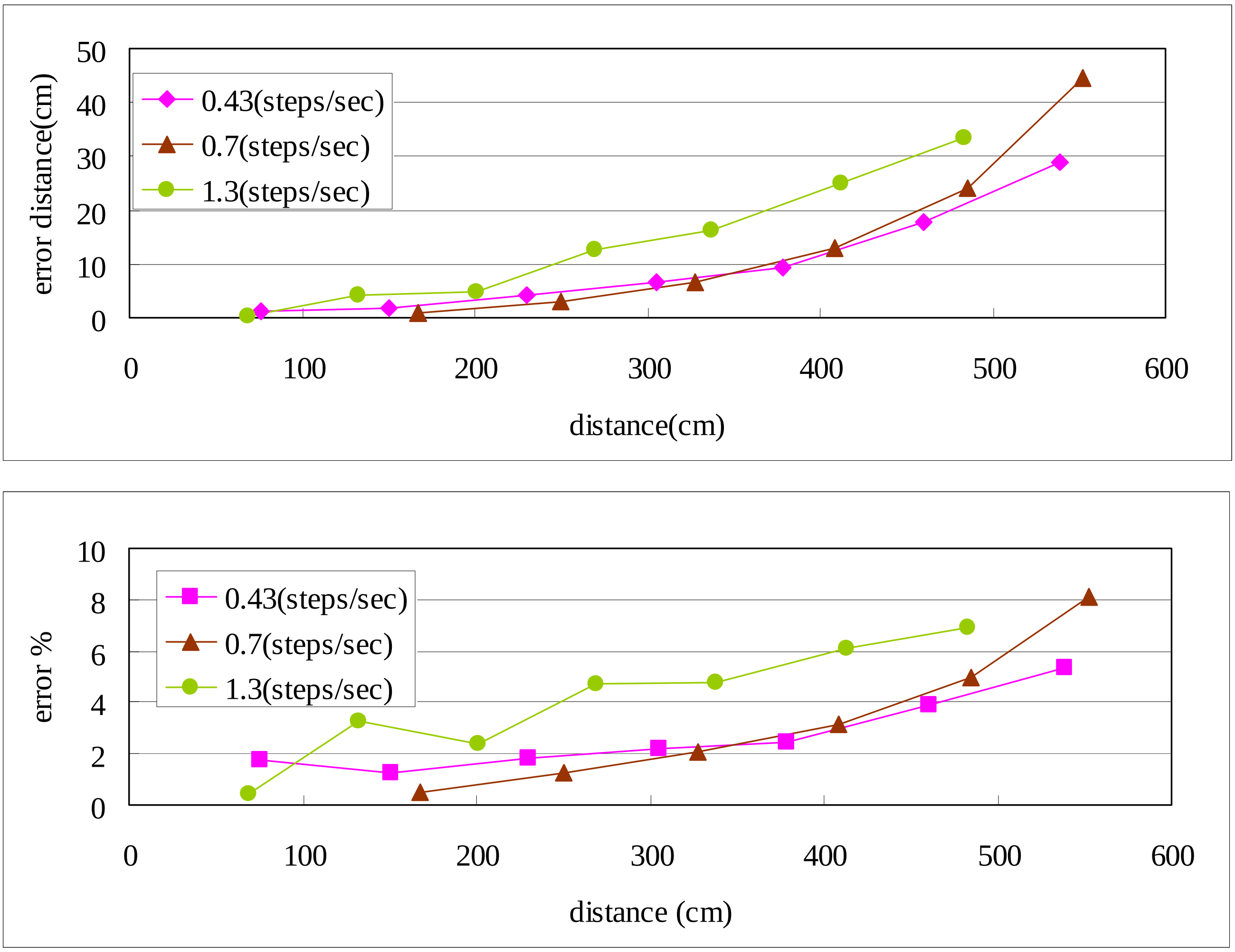


Figure 3.5: The positioning accuracy (error) under different walking speeds over the walking distance

Chapter 4

Revised design: Design Version III

Design III tries to fix the error accumulation problems in design II. Design III incorporates location-aware passive RFID tags and readers that can reset the accumulated error whenever the user steps on top of a RFID tag with a pre-determined location coordinate. These location-aware passive RFID tags forms a passive RFID grid that can be used to bound the accumulated error in design II. Since a higher RFID grid density means higher probability that a user will step on top of a passive RFID tag (therefore resetting the positioning error), the ideal density of the RFID grid can be chosen to achieve the needed positioning accuracy in the deployed environment.

The RFID solution has two parts:

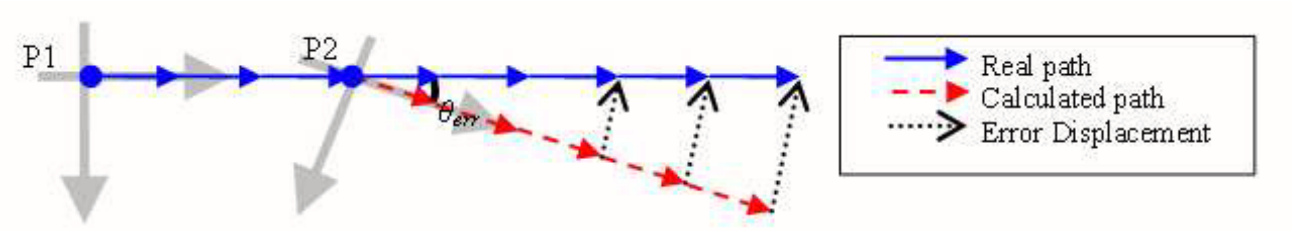
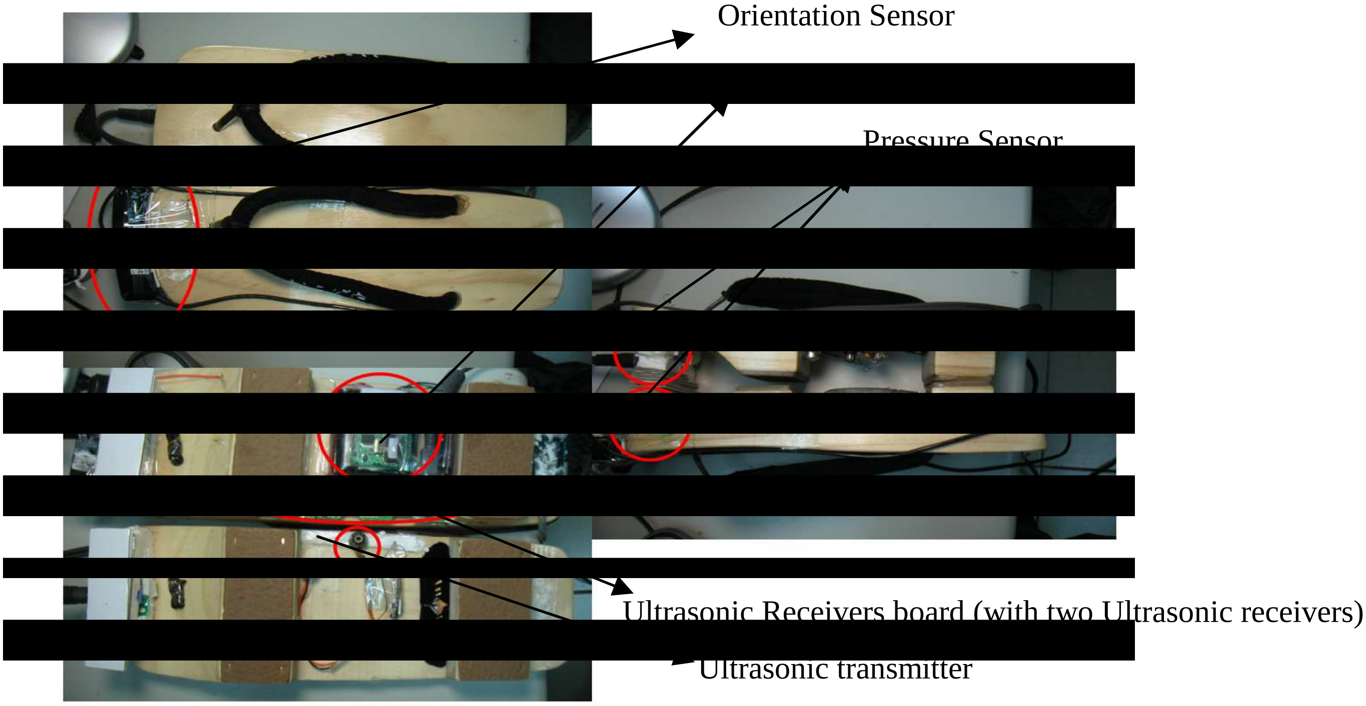


Figure 4.1: illustration of the accumulation of the error of θ



[redacted]

Figure 4.2: It shows the prototype of final design (version III) of the GETA sandals. Prototype of design (version II) does not have the RFID reader. Prototype of design (version I) does not have the orientation sensor but has an additional transmitter.

1. a Skyetek M1[4] RFID reader is installed at the bottom of the left sandal,

2. a set of passive RFID tags with the read range of 4.5 cm are placed in the grid fashion.

We only attach one additional RFID reader to the left sandal, and the other device configuration is the same as in design II (Fig. 4.2.)

In the target environment, a server is used to maintain the table mappings between RFID tag IDs and corresponding location coordinates. When a user enters the target environment, the GETA sandal downloads its mapping table. The positioning algorithm is revised as follows. When the

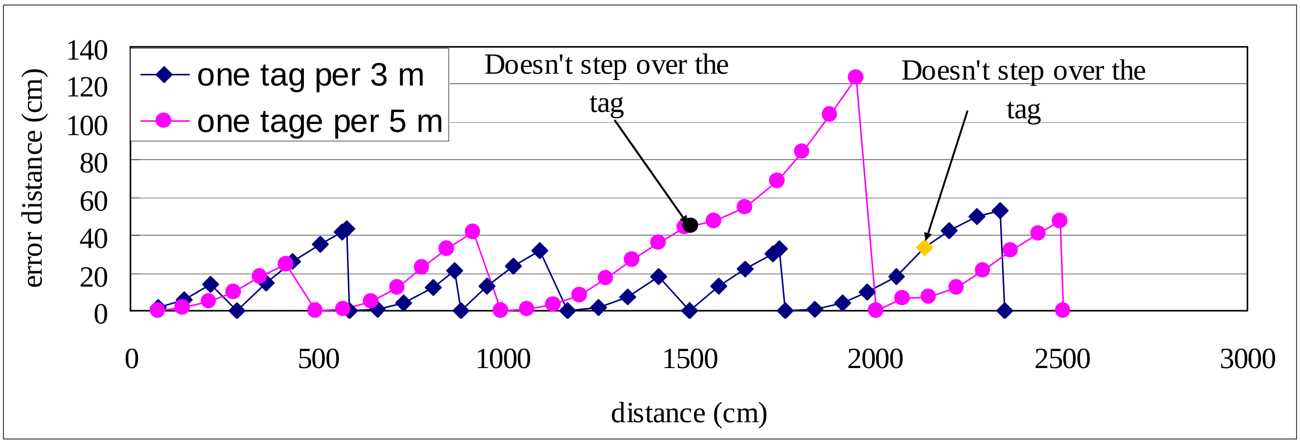


Figure 4.3: The positioning accuracy (error) under different walking speeds over the walking distance.

GETA sandal steps on top of a RFID tag, it looks up the cached mapping table to find the location coordinate of this RFID tag. Then, the current location of the user is set to the location coordinate of this RFID tag rather than from the footprint tracking method.

4.1 Performance Evaluation

We have evaluated the performance of GETA sandal (version III) in a 15x15 square meters testing environment. We have two different configurations of passive RFID grids. The first configuration places one tag every 3m, and the second configuration places one tag every 5m. Fig. 4.3 shows the measured positioning error over walking distance for these two configurations. The error is reset to zero when a user steps on top of a RFID tag. Fig. 4.3 also shows that under a random walk, there is a probability that a user may not step on a RFID tag every 3m or 5m. As a result, the errors continue to accumulate past 3m or 5m until a user eventually steps over a RFID tag.

Chapter 5

Conclusion and Future Work

This paper describes the design, implementation, and evaluation of our footprint-based indoor location system on traditional Japanese GETA sandals. Our footprint location system can significantly reduce the amount of infrastructure needed in the deployed indoor environments. In its simplest form, the footprint location system is contained within the mobile GETA sandals, making it easy for everywhere deployment. The user simply has to wear the GETA sandals to enable his/her location tracking with no efforts in calibration and setup. In addition to the benefit of being low infrastructure cost, the footprint based method does not have problems in infrastructure-based indoor location systems such as noises, obstacles, interferences, and dead spots. Although the footprint based method can achieve high accuracy per moving footstep, it has a problem that positioning error can be accumulated over distance traveled. As a result, it may need to be combined with a light RFID infrastructure to correct its positioning error over some long distance traveled. There are two yet-to-be-addressed problems in our current prototype of GETA san-dals: wear-ability, RFID tag placement, and stair climbing. The current wear-ability is unsatisfactory due to interconnecting all sensor components to a Notebook PC through hardwiring. In our next prototype, we would like to replace all hardwiring with wire less networking (e.g., Bluetooth), and replace processing on the Notebook with a small embedded processor. To further reduce the RFID infrastructure, we are interested to locate strategic frequently visited spots in an environment and to place these RFID tags. Stair climbing is a serious problem because the stair becomes the obstacle blocking the sensors between two sandals. To address this problem, we use the strat-egy of putting RFID tags at the entrances of the stairs. We can treat a stair as a transition path from one floor space to another. Then we can use the RFID to know when we move into or out a stair and change the position to the new floor space.

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