



Movement tracking system with embedded devices in shoes

Field of the invention

The present invention relates to the field of movement tracking, and more particularly to that of location-aware systems in which individuals moving (e.g. walking or running) within an environment are tracked.

Background of the Invention

Many location-aware systems (that is, systems for tracking the location of a mobile user) have been proposed in literature, but most of them are low accuracy systems with a resolution on the level of meters. They require at least three fixed stations as the infrastructure for 2D positioning, and at least four for 3D positioning. They cannot provide orientation information about the user, such as the direction in which he or she is facing which provides clues about the current object of the user's attention. Furthermore, they are partially obtrusive to the user's movement as at least a tag needs to be clipped to the user's clothes or hung around the user's neck.

An active badge location system proposed by Roy Want and et al in "The Active Badge Location System" makes use of IR tags together with a sensor network to link the user's location to the nearest sensor. It requires "adequate placement and density of the sensors" and is used for low accuracy applications to the level of a room, and the accuracy depends on sensor density.

The RADAR system proposed by P. Bahl and V. N. Padmanabhan in "Radar: An in-building RF-based User Location and Tracking System" operates by recording and processing RF signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. It requires at least 3 base stations for triangulation and the accuracy is meter level.

In "Parasitic Power Harvesting in Shoes" by J. Kymissis and et al, an RFID system was built utilizing the harvested power from user steps. It is shown that a peak power of roughly one Watt and an average power of a quarter Watt can be generated by normal human walking. The system includes RFID tags to be attached to each of a pair of sneakers and one RF receiver. The user's steps power up a power-conditioning circuit which will activate a RF transmitter when enough power is harvested. However,



this RFID system operates at 310MHz and is only able to provide vicinity information as it only can detect whether the sneaker's ID is read or not: not the direction of the RFID tag relative to the RF receiver.

5 “The GETA Sandals: A Footprint Location Tracking System”, the footprint-based indoor location system proposed by Kenji Okuda and et al, works by measuring and tracking the displacement vectors along a trail of footprints with ultrasonic-infrared-combo sensors. The position of a user is calculated by summing up the current and all previous displacement vectors. The greatest disadvantage is the accumulation error inherent from the working principle. Though some re-calibration method can be applied
10 (e.g. RFID grids), this will lead to additional infrastructure cost.

 The AshiNavi system proposed by Shunsaku Yamazaki and et al in “AshiNavi: A Footprint-based Ambient Navigation System” is designed for a natural navigation system. Based on the current position of the user, which is detected by a commercial ultrasonic location system which again requires the deployment of a sensor array with
15 adequate density, footprints towards the user's intentional direction are shown by a projector to navigate the user.

 In “The Smart Floor: A Mechanism for Natural User Identification and Tracking” by Robert J. Orr and Gregory D. Abowd, a system has been proposed for identifying people based on their footstep force profiles.

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Summary of the Invention

 The present invention aims to provide a new and useful positioning system to determine the locations of one or more individual users.

25 In general terms, the present invention proposes that multiple spaced-apart antennas controlled by at least one RF (e.g. UWB) transmitter are embedded into a shoe. Optionally, both of a user's shoes include such antennas.

 Preferred embodiments of the invention make possible high accuracy position tracking, providing information about the user's 2D position and the orientation of each of his or her feet. The tracking may be accurate enough to differentiate each footprint.
30 In preferred embodiments, it requires only one single fixed station system, and thus has easy setup.

Preferably, the antennas and RF transmitter are embedded into the sole portion of the corresponding shoe. This provides a total unobtrusive experience to the user since the user might not be even aware of the device embedded in the shoes.

Optionally, a force sensor can be included in the embedded system to collect
 5 ground reaction force (GRF) information and transmit it wirelessly from the tag to the fixed station utilizing the communication ability of the proposed system. This additional information can be used for finer analysis of the user's movements.

Optionally, the tracking system can be self-powered. Without any requirement for batteries, the tag's power can be harvested from the user's stepping movement
 10 unobtrusively during walking or running.

Brief Description of the Drawings

Embodiments of the invention will now be described for the sake of example only with reference to the following figures in which:

15 Fig. 1(a) is a schematic illustration of an embodiment of a positioning system in the Singapore patent application 200605527-1.

Fig. 1(b) and 1(c) show graphs of example waveforms received at two receiving antennas in Singapore patent application 200605527-1;

Fig. 1(d) is a schematic illustration of the coordinate system in Singapore patent
 20 application 200605527-1;

Fig. 2 is a schematic illustration a system which is a first embodiment of the invention, comprising a mobile transmitter and a fixed receiving station.

Fig. 3 is an illustration of a system which is a second embodiment of the invention, including a force sensor collecting GRF data.

25 Fig. 4 shows another embodiment of the invention in which a UWB tag with a battery is embedded in a shoe.

Fig. 5 shows another embodiment of the invention in which a UWB tag with a power harvesting subsystem and a power storage subsystem is embedded in a shoe.

Fig. 6 shows another embodiment of the invention in which a UWB tag with a
 30 force sensor is embedded in a shoe.

Fig. 7, which is composed of Figs. 7(a)-7(c), shows graphs of typical GRF profiles.

Fig. 8 shows one possible structure of a force controlled mechanical switch for use in an embodiment of the invention.

Fig. 9 is a block diagram of the transmitter circuit.

Fig. 10 illustrates the format of a packet which a transmitter in an embodiment of the invention may transmit.

Fig. 11 illustrates an intelligent information service application employing an embodiment of the invention.

Fig. 12 shows an application employing an embodiment of the invention in basket ball court.

Fig. 13 shows an intelligent home appliance service system which is an application of an embodiment of the invention in a home environment.

Detailed Description of the embodiments

1. Summary of UWB positioning techniques which may be employed in the present embodiments

A description will now be given of UWB positioning techniques disclosed in three earlier Singapore patent applications. These positioning techniques have not, to our knowledge, been publicly disclosed in the field of the present invention (i.e. location-aware systems), and may thus be considered as lying in a different technical field. It is for this reason, and also because it is believed that two of the applications were not in the public domain at the priority date of the application, that they are not described in the "background of the invention" section above.

In Singapore ("SG") Patent Application SG 200504866-5, a UWB positioning system based on mono-pulse concept has been proposed. Using this system, the 2D position of a mobile "responder" can be estimated by a single fixed "requestor" using ranging and direction of arrival (DOA) estimation. This application had been laid open by the priority date of the present invention, and its disclosure is incorporated herein by reference.

As an enhancement of the above application, in SG Patent Application 200605527-1 (the disclosure of which is also incorporated by reference), a related

positioning system and method is proposed with two additional features: orientation can be estimated together with 2D position, and there is only one-way data transmission from the mobile “tag” to the fixed station. The present embodiment described below provides a novel application and design based on SG Application 200605527-1, and
 5 fully utilizes these two features.

SG Patent Application 200605527-1 proposes a positioning system in first and second UWB devices determine the position of the first UWB device relative to the second UWB device or vice versa. Fig. 1(a) illustrates the positioning system. The first UWB device 10 has two or more omni-directional antennas 1 and 2 spaced apart by a
 10 predetermined distance. The second UWB device 11 has one or more directional antennas A and B. The system determines the relative position based on the pulses sent between the antennas, and knowledge of the predetermined distance.

The relative position may be expressed as a triplet (d, α, β) where:

d is the relative distance, defined as the average range from the omni directional
 15 transmitting antennas of the first UWB device to the second UWB device.

α is the relative angle, defined as the average DOA of the omni directional transmitting antennas of the first UWB device relative to the second UWB device.

β is the relative orientation, defined as the angle of the axis joining the omni directional transmitting antennas of the first UWB device, relative to the second UWB
 20 device.

To determine the position of the first UWB device relative to the second UWB device from at least two UWB pulses received at the second UWB device from the first UWB device, a plurality of parameters are extracted from the two UWB pulses by signal processing. In the preferred embodiment, 6 parameters or features illustrated in
 25 Fig. 1(b) and 1(c) are extracted. The extracted features include four amplitudes:

- A1A (corresponding to the pulse 12 from first transmitting antenna 1 to first receiving antenna A),
- A2A (corresponding to the pulse 13 from second transmitting antenna 2 to first receiving antenna A),
- 30 • A1B (corresponding to the pulse 14 from first transmitting antenna 1 to second receiving antenna B) and

- A2B (corresponding to the pulse 15 from second transmitting antenna 2 to second receiving antenna B)

and two time differences or delays:

- ΔA 16 (the delay between the pulses 12, 13 from first transmitting antenna 1 and second transmitting antenna 2 to reach first receiving antenna A) and
- ΔB 17 (the time difference between the pulses 14, 15 transmitted by first transmitting antenna 1 and second transmitting antenna 2 to reach second receiving antenna B).

10 Based on these parameters and the predetermined distance, the angle α , distance d and orientation β of the first UWB device relative to the second UWB device is determined. Fig. 1(d) shows the coordinate system between the transmitting antennas 1 and 2 relative to the receiving antennas A and B which is used to define the relative position.

15 SG patent application 200602425-1 (the disclosure of which is incorporated by reference) proposes a method for estimating one or more parameters of a received UWB signal by inhibiting the effects of multipath interference, to obtain an estimated value or values for the parameter or parameters. Briefly, the technique operates as follows. Firstly, the method estimates the parameter(s) for a first signal element in a received
20 signal, then subtracts this signal element from the received signal to obtain a modified signal. The parameter(s) for a number of further signal elements are then estimated and these elements are removed from the modified signal to form a refined signal. The parameter(s) for the first signal element are re-estimated to re-define the first signal element based on the refined signal minus the signal element having the greatest
25 amplitude. The parameter(s) for the signal element having the greatest amplitude are re-estimated to re-define this signal element. The steps are repeated to generate a refined estimate of the parameter(s) for the first signal element. There is also disclosed a receiver for performing the above steps.

30 2. Description of embodiments

Fig. 2 illustrates the setup of a system which is an embodiment of the present invention. Its basic elements include a fixed UWB receiving station 100 and mobile UWB tags 101 embedded in the sole of one or more respective shoes (one shoe is shown for simplicity). The UWB tag 101 embedded in each shoe comprises a UWB transmitter 105, a force controlled switch 108 and a power system 109. Two omnidirectional antennas 106, 107 are installed at respective ends of the shoe. With each step the user makes, the GRF received by the force controlled mechanical switch 108 will trigger the UWB transmitter 105 to transmit a train of UWB signals to be sent out by the two antennas 106, 107. The UWB transmitter 105 and the force controlled switch 108 are powered by a button battery or the power harvesting system 109 which transforms kinetic power of the user into electricity, and possibly with a power storage system to store this power. At the fixed UWB receiving station 100, an antenna array 102 made up of at least two directional antennas 103, 104 collects the UWB signals transmitted by the mobile UWB tag 101 and passes the signals to the UWB receiver 100 for analysis. A signal processing unit 111 of the UWB receiver 100 analyzes the signals collected by the antenna array, such as with the method proposed in the SG patent application number 200605527-1, and determines the distance, angle and orientation of the mobile UWB tag 101 to the UWB receiver 100. Thus the position and orientation of each shoe is determined.

The arrangement of embedding the transmitting tag into the shoes has the advantages of total unobtrusiveness, posture awareness as the orientation of each of the shoes is naturally associated with the user's posture, and power intelligence as the tag naturally works only when the user moves. Furthermore, this arrangement also provides the possibility of harvesting power from the user's movement and thus a battery is not required.

Fig. 3 shows a second embodiment of the invention. In this embodiment, the function of recording the user's GRF data is realized. A force sensor 200 embedded in the shoe, possibly in the sole portion, produces a digitized profile of the GRF of the user during one step. These data are then encoded and modulated on the UWB pulses, and can be fitted into the packet format as shown in Fig. 10 (described below). At the receiver side, these data can be demodulated and decoded for further analysis. This GRF data is useful for user identification in many applications.

In a preferred embodiment of the present invention, a power harvesting subsystem is used to utilize the kinetic power of the user's own movement. This system can be similar to that introduced by Robert J. Orr and Gregory D. Abowd, but in contrast to that proposal the transmission of UWB pulses in the present system is not triggered as soon as enough power is harvested. In the present embodiment, transmission is always synchronized with the user's steps by the force controlled switch to make sure the position and orientation are always measured when the shoe is in contact with the ground. An additional power storage block may be provided.

Fig. 4 shows a further embodiment with a UWB tag installed in a shoe. UWB technology is famous for its simplicity and its low power consumption. It has been reported that an integrated battery operated UWB tag could have a size on the cm^3 level, and thus the circuit part can be easily hidden in the sole. Its low power consumption allows the tag to be operated by battery for a long period, for example, half a year, or allows it to be operated by the power entirely harvested from the user's GRF. The transmitter 301, battery 302 and switch 300 are all embedded into the sole of the shoes. The antennas 303 used are omni-directional, which can have a planar design with very small size. For example, the one shown in the Fig. 4 has a planar design of $30 \times 30 \times 0.8$ mm. It is possible to further reduce the size to $10 \times 10 \times 0.8$ mm. Two of such antennas are to be attached on the surface of two ends of each of the shoes to provide the greatest displacement for increased orientation estimation accuracy. In addition, as proposed in SG Application 200605527-1, the RF paths to these two antennas are preferably made to be different via an asymmetric geometry arrangement or an additional delay circuit for one path.

Fig. 5 shows a further embodiment with a UWB tag embedded in the shoe with a power harvesting subsystem 401 and a power storage subsystem 402.

Fig. 6 shows a further embodiment with the UWB tag embedded in the shoe with a force sensor 501.

In SG Application 200605527-1, the method requires the geometric displacement between the antennas to be fixed and pre-known. For the present embodiment, this distance is variable according to different sizes of the shoes. One solution is for the (quantized) possible distance values for different shoe sizes to be

stored as part of the ID information encoded in the packets, and transmitted wirelessly to the fixed receiving station for use in the calculation.

The UWB transmitter sends out short pulses in trains or packets when the force-controlled switch is turned on in each step the user makes. Fig. 7 shows typical GRF profiles. In Fig. 7(a), the GRF profiles of both the vertical and lateral components during walking are shown (extracted from “Examining human walking characteristics with a telescopic compass-like biped walker model” by Miyakoshi, S. and Cheng, G.). The solid (darker) and dotted (lighter) lines correspond to the right and left foot respectively. For each foot the vertical and lateral forces are zero between the steps, thus each step corresponds to lower line showing the lateral force and an upper line showing the vertical force, these lines meeting at 0% at the start and end of the step. For example, a step of the right foot extends from about 4.40s to 5.5s, during which time the vertical force has two peaks each about 0.25s wide, and the lateral force has rapid fluctuations. The values are all normalized to the body weight.

In Fig. 7(b), the GRF profile of vertical component during running is shown (extracted from “Kinetic consequences of constraining running behavior” by John A. Mercer and et. al.). In Fig. 7(c), the GRF profile of vertical component during jumping is shown (extracted from “Contribution of non-extensor muscles of the leg to maximal-effort countermovement jumping” by Akinori Nagano and et. al.). The solid and dotted curves correspond to two jumping modes: “extensor only” and “all muscles” respectively. The dashed horizontal line illustrates the body weight of the user. From Fig. 7, it can be estimated that the transmitter circuit can be turned on for at least about 150 milliseconds in each step, either during walking, running or jumping. This is enough for the UWB transmitter to send out about 1 million pulses for synchronization, ID detection and amplitude measurement.

The force controlled switch can take a variety of designs. The main function is to activate the pulse transmission only when a step is made. By studying the GRF profiles of different people in different movement modes, such as those illustrated in Fig. 7, an appropriate threshold value can be selected for the “switching on” and the switch can be design accordingly.

Fig. 8 shows one possible structure of a force controlled mechanical switch. A portion 701 maintained at a first (e.g. negative) potential includes a contact portion 702.

The portion 701 is flexible, with its sides (as shown in the diagram) fixed to the portion 704. When the switch is compressed by compressive force in the vertical direction, the portion 701 flexes so that the contact portion 702 contacts the corresponding contact portion 703 of a second portion 704 of the switch which is maintained at a second (e.g. positive) potential.

Fig. 9 is a block diagram of the transmitter circuit together with its connection with the antenna 801 (only one is shown for simplicity, though in fact the transmitter circuit feeds the signal it generates to two antennas by a power divider, for example), battery 802 and the force controlled switch 803. The baseband circuit 804 performs the coding, modulation and packet forming, and generates the trigger signals, for example, rising edge, for each and every pulse; the pulse generator 805 generates one short duration pulse, about 1 nS, with the arrival of each trigger signal; and the filtering and amplification part 806 makes the pulse fit into the FCC spectrum mask with an appropriate amplitude. Lastly, the pulses are transmitted into air through the antennas 801.

The pulses from the transmitter can be arranged in packets. One example of packet format is shown in Fig. 10. The acquisition preamble 901 provides information for the fixed station to “lock in”. The ID data 902 is used to differentiate each transmitter. The waveform pulses 903 are used for the fixed station to get the waveform sample for signal processing. The communication data 904 includes other information, such as GRF data in certain applications, to be encoded and transmitted to the fixed station. If multiple users are moving at the same time, to reduce the possibility of “collision” of UWB packets in the air, a pseudo-random time-delay can be included in each transmitter.

At the fixed receiving station side, the antenna array may be put at a height about the same as the omni-directional antenna attached to each shoe in order to get the maximum gain. Since the antennas are working near to the ground, a multi-path problem may exist in some applications. However, it can be solved, or at least alleviated, by method proposed by SG Patent Application 200602425-1 (summarized above).

The total number of users that one fixed station can simultaneously track depends on two factors: the length of the frame structure and the user’s pace frequency.

Both these two factors are application dependent, but based on experiments, a single system can easily achieve simultaneous tracking of 5 users or 10 tags, with the assumption that the pace frequency of the user is less than 10 Hz. The purpose of the system is not to track the whole trajectory of the user, which might be very fast and requires high speed updating rate, such as in a basket ball court application. Instead, the system is more focused on “snapshots” of the movement when the user’s feet are in contact with the ground and uses this information as an interface for context aware applications.

With the above system, the real-time footprint with the GRF data of a user can be detected. Further analysis can reveal the user’s current status such as position, facing direction and posture. This kind of information enables many new context aware applications to be developed. For example, location and facing direction based content service, interactive gaming and animation film making and etc. The power harvesting possibility of this system also enables it to be embedded into each and every pair of shoes without a risk of a battery running-out or requiring re-charging.

One example of the application of one embodiment of the invention is shown in Fig. 11 as an intelligent information service in large exhibition area, such as a museum. The positioning system 1000 determines the user’s current position and the direction he or she faces and passes it to an information center 1001. The information center then provides related information, such as navigation guidance, or multimedia information on the artifacts the user is facing, to the user through other wireless channels, such as a wireless headphone or a mobile phone.

Fig. 12 shows another possible application in professional sports. The working field is set to be a basket ball court 1100 in the NBA. The positioning system consists of one pair of shoes installed with the abovementioned UWB tag and a fixed station 1101 to be easily installed near the court. The shoes are to be worn by one player under analysis. During a game, the player’s movement, posture and weight balance are recorded through the force sensor embedded. These data can then be correlated with a video tape to analyze how to improve the player’s performance through targeted training. With the whole team wearing such devices, it is possible to further analyze the real-time team formation during games and improve the training for new strategies.

Fig. 13 shows an application of an embodiment of the invention in the home environment. The application aims to provide a valuable service to the users by coordinating networked home appliances. Every user in the home wears a pair of shoes, each with the proposed UWB tag and antennas. The receiving station 1200 is connected
5 to a home server 1201 which can control all the home appliances 1202 within the home through a wired or wireless network infrastructure. The service is provided to the users based on the context related to their position, the direction they face and possibly also the GRF information. For example, stomping one of the feet in certain way can be designated as a means to “ask” for certain service. A simple example is to provide video
10 service on the nearest display device, such as TV, computer screen, or a mobile phone screen, to the user based on his or her position and the direction he or she faces. Another example is a universal remote controller that automatically changes its interface and functions depending on this same information. The same remote controller works on the TV if the user is sitting on a sofa and facing the TV, whereas it controls the air-
15 conditioner if he or she is in the bedroom. The server might also control several appliances at the same time to provide the integrated service. For example, in the previous TV controller example, if the server detects the user to be sitting on the sofa and facing the TV, it may adjust the lights and air-conditioner at the same time to provide the user with a preferred ambiance for watching TV.

20 Although only a few embodiments of the invention have been described above, many variations are possible within the scope of the invention as defined by the claims, as will be clear to a skilled reader.

Claims:

1. A movement tracking system comprising:
one or more shoes, each shoe comprising a plurality of spaced-apart omni-
5 directional antennas and at least one RF tag for generating RF signals for transmission
by the antennas;
a fixed RF receiver station comprising one or more directional antennas, and a
processor for determining the position of the shoes relative to the receiver station.
- 10 2. A system according to claim 1 wherein the processor is programmed to obtain
from the signals received by the directional antennas, the angle, distance and orientation
of the shoes relative to the fixed RF receiver station.
3. A system according to claim 1 or claim 2 in which in each shoe the RF tag is a
15 UWB tag for generating UWB signals, and the RF receiver station is for receiving
UWB signals.
4. The system according to claim 3 wherein, in each shoe, the UWB tag includes a
UWB transmitter unit arranged to generate an UWB pulse and to pass the UWB pulse to
20 each of the omni-directional antennas.
5. The system according to claim 4 wherein each shoe further includes a force
sensor which gathers the GRF (ground reaction force) data and transmits it to the UWB
transmitter unit, the transmitter unit being arranged to encode the GRF data within the
25 UWB pulses.
6. The system according to claim 4 or claim 5 wherein each shoe further includes a
force controlled switch which turns on the transmitter unit when the GRF exceeds a
threshold value.

7. The system according to any of claims 4 to 6 wherein each shoe further includes a power harvesting subsystem which transforms the kinetic energy of the user's movement to electrical energy and supplies the electrical power to the UWB tag.

5 8. A shoe for use in a movement tracking system, the shoe comprising a plurality of spaced-apart omni-directional antennas and at least one RF tag for generating RF signals for transmission by the antennas.

9. A shoe according to claim 8 in which the RF tag is a UWB tag for generating
10 UWB signals

10. A shoe according to claim 9 wherein the UWB tag includes a UWB transmitter unit arranged to generate an UWB pulse and to pass the UWB pulse to each of the omni-directional antennas.

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11. A shoe according to according to claim 10 which includes a force sensor which gathers the GRF (ground reaction force) data and transmits it to the UWB transmitter unit, the transmitter unit being arranged to encode the GRF data within the UWB pulse.

20 12. A shoe according to claim 10 or 11 which includes a force controlled switch which turns on the transmitter unit when the GRF exceeds a threshold value.

13. A shoe according to claims 9 to 12 which further includes a power harvesting subsystem which transforms the kinetic energy of the user's movement to electrical
25 energy and supplies the electrical power to the UWB tag.

14. A shoe according to any of claims 8 to 13 in which the antennas and tag are located in a sole of the shoe.

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