User tracking by sensorfusion for situation aware systems

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Abstract
Context-aware applications for mobile computers (PDA´s) need a high quality of globally sensor input. Multimodal sensor systems as well as tracking of location, userprofile and environment changes are trying to archive new and better possibilities for the interpretation of the user´s interaction with the environment. Some relevant solutions of high accuracy tracking systems do already exist. The task of a functioning indoor navigation has been solved by a complex and high-end realization. This report describes an approach of a low budget but efficient user-tracking-system. This system is realized by sensorfusion and the use of very inexpensive components and standardized PDA´s. The concepts of a location dependent situation aware system with PDA´s became basically visible by the eGuide, the official electronic congress guide for the Palm Europe Developer Conference (manufacturer of the Palm Computers) in Amsterdam 2001.

Introduction

During the last years we can notice the incredible increase of mobile devices to support the user. Cellular phones are spread and accepted in our society, handheld organizers are widely common and pervasive computers are conquer our everyday live. The availability of really handy mobile computers presents a new kind of applications, the mobile assistance. Especially for large exhibitions, which can expand an area of more than 400.000 qm with more than 8.000 exhibitors a mobile navigation guide becomes a must. But not only for congresses or large trade fairs is a need of an personalized orientation system. Even for airports and for the shopping mart next door we can find the application field of a personal navigation system. The Fraunhofer Institute of Computer Graphics Rostock developed a personal guide on the platform of PDA's, (personal digital assistant) to assist the user by personal mobile navigation. That personal information system was presented at the CeBIT 2000 as the first official electronic exhibition guide (eGuide) for palmsized computers and was thereby founding a new generation of personal assistant for fairs and exhibitions[1]. A useful mobile visualization of the destination implies a precise and robust location system. Blackouts of the sensors (e.g. GPS signal lost) has to be compensated. This can be archived only by suitable sensors and input systems.

1 Motivation

Useful applications for context aware mobile assistance need an appropriate environment monitoring. Palmsized PC´s like the PDA are widely common but only equipped with a poor sensorsystem (e.g. infraredsensor, communication ports and user interface). To find the own position it would be necessary to cover the area by a encircled location network like e.g. GPS, cellular networks (GSM, bluetooth cells etc) or beacons.
Existing systems are using a wide range of techniques to track the user's position. Indoor tracking systems need an specific and complex infrastructure to archive the needed information. Standalone systems which are tracking the personnel on foot mostly do not have the variable accuracy which might be needed. Inhouse dead reckoning systems are using acceleration sensors only as pedometers because of the integral error. But the touch of a show on the ground (zero speed) implies deep information about different spatial functions. The velocity before the touch down differs by each user speed and profile. Also the drift by the speed integration can be recalibrate every step. This causes a linear error of the tracking algorithm. By the smart use of standard devices and the combination of traditional techniques, an efficient navigation tool can be created which can provide the needed data for further applications and location management systems.

2 Related Work

Dead Reckoning (DR) is the process of estimating the position by advancing a known position using course, speed, time and distance to be traveled. This is not only a domain for the humans, also primitive animals like ants do dead reckoning as well[3]. The history of DR started by aerial and nautical navigation. Nowadays DR is needed for outdoor and indoor Augmented or Virtual Reality (AR/VR) Systems. Inertial sensors are sourceless and relatively immune to environmental disturbances. Their main problem is drift, the accumulation of error with time. Recovering orientation changes (through rate gyroscopes) is easier than position changes (through linear accelerometers) because the former requires only one integration step, while the latter requires two. Ships and aircraft have inertial measurement units that drift a fraction of a degree per hour in orientation and under one nautical mile per hour in position. However, these sensors seems not appropriate for a single user walking around outdoors, due to cost and weight. Rate gyros of the form factor appropriate for a human exist and may be sufficient for shorter time intervals (minutes or seconds). With high efforts the PointMan™ Dead Reckoning Module (DRM™) has been developed. This is a miniature, self-contained, electronic navigation unit that provides the user's position (Latitude/Longitude) relative to an initialization point. The PointMan™ DRM™ is the first practical implementation of a drift-free dead reckoning navigation system for use by personnel on foot. It is specifically designed to supplement GPS receivers during signal outages. It even works inside of many buildings but does not support a varying step length[4]. Augmented and Virtual Reality does need a high precision for indoor user tracking, systems like ultrasonic ceiling tracker by e.g. InterSence are able to track in range of centimeters[5], active badge systems founded by the Olivetti & Oracle Research Laboratory (ORL), now At&T[6] are also in use. The beacon technology by infrared has been improved by various institutes[7]. Some robots research centers are dealing with optical recognition systems[8] or radio frequency identification. Unfortunately we can notice that beacon or cellular systems need a certain infrastructure and are not usable for unprepared areas. The recent solution of an accuracy navigation is the use of sensorfusion techniques to combine different sensor types (e.g. graphical recognition systems) to improve the performance of the navigation systems[9], the military research centers are also implementing remarkable solutions[10].

3 Spatial User Profile

Figure 1: dynamic user profile by location

The change of locations and the moving in itself can give information about the users profile, goals and wishes[11]. This information can give a user profile of walk habits, biological characteristics and ergonomically data. The needed resolution and accuracy of the location system depends by the task a user tries to archive. Every user is effected by the surrounding and so the movements of the user are influenced by the environment itself. When we archive information about the movements we are also getting indirect information about the situation and the circumstances[12]. If we would know every move of a visitor at a car show, we are able to find the user profile of the visitor by regarding which cars (e.g. sport cars or commercial motor vehicles) he was looking to. For the international car show IAA´99 (Frankfurt/Germany) the Fraunhofer IGD Rostock developed for one car company (BMW) an exhibit-guide and tracked the positions of the user by infrared beacons.

To cover the entire booth more than 100 infrared beacons were needed. The advantages of the infrared beacons are in the compatibility with the standard IrDA protocol so that every standard device (Notebooks or PDAs) can use it, the other advantage is capability to detect the direction of the user because of the line of sight characteristic of the infrared light.

The interaction between human and computer normally takes the five senses. The five primary human senses - sight, hearing, touch, taste and smell - can be input/output channels for communication between humans and computers[13]. Traditionally the communication between human and computers will set up on the same type of communication levels human are used to communicate among each other. The primary form of human-to-computer communication based on hearing is voice recognition technology. The primary form of human-to-computer communication based on what we can see is gesture recognition technology. Gesture recognition includes computer recognition of hand gestures and sign language, body stance and movement, full facial expressions and (in the future) perhaps lip reading as well. A communication between human and computer can also be different like human act to each other because computers can remember, are ubiquitous and concentrated 24 hours per day[14].

4 Acceleration Sensors

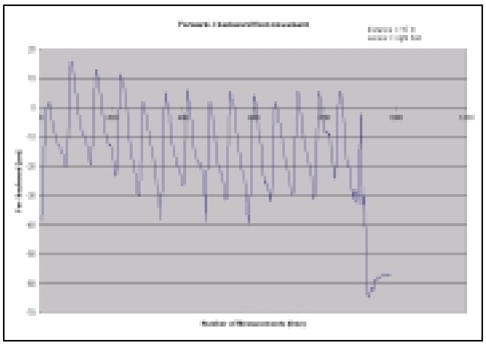

Figure 2: step-length of a test person

When we want to explore what a human can tell to the computer between the lines we have to look more detailed to the talk. Because of the important role of the location for the situation aware we will concentrate on the user´s location. Whenever it is important to know the location of a user and no location network can be used (e.g. GPS etc) an alternative location system is needed. For this purpose dead reckoning systems can be used. By counting the steps of a user, measuring the direction and duration of walk, the location can be found quite accuracy[15]. Parts of personal dead reckoning systems like pedometers are mainly used for measuring long distances, because of the balance of the varying step-length. We can expect an error of less than 2-5% because the step length can be considered as a constant value. By biomechanics we know that the user´s age, sex and sized is affecting the parameters of the step length. When we look to the body movements while walking, it´s obvious that a step-length is not constant at all - even a person tries to walk constantly through an even floor of a building. As we could figure out the step-length increases by the speed of walk. The following figure shows the step-length of a person, taken by a capacitive acceleration sensor in our Institute. The reference point is mounted at the hip (belly button), the motion sensor is at the tip of the foot.

When we look to the motion of the foot itself, we can see that the foot is also doing movements to the side as shown in figure 3.

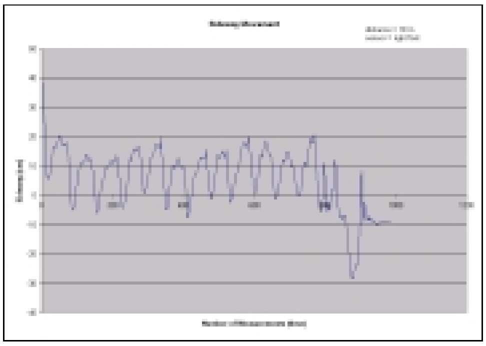

Figure 3: sideways motion of the foot

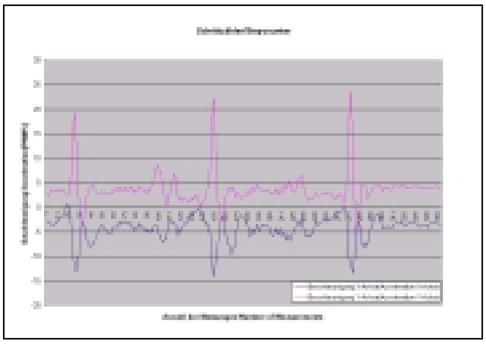

Figure 4: acceleration of the user´s hip

The walk is only effecting the feet and legs, the entire body inclusive the arms are moving. A sensor mounted at the hip can give the exact starting point of a step. Mechanical pedometers are working by that function. In figure 4 we can see the peeks of the acceleration of a human hip while doing three steps.

5 Sensorfusion

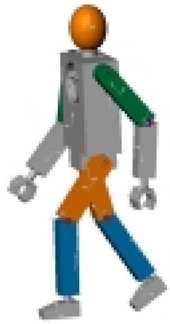

Figure 5: Human model

Dead reckoning systems are calculating the present location from a known position plus the movement by direction and way. Unfortunately the error of the calculation will constantly increase as longer the distance will be. With the combination of several sensors the error can be less or even negligible. A read reckoning system only basing on the acceleration of the human will unusable after a couples of seconds. Just using pedometers are not precise in short, not linear and irregular walks. For this application field it would be nice to know the real step length. As shown before an ultrasonic or electromagnetic tracking system can be used, but this equipment is expensive and not really wearable. To use standard devices we can integrate the an acceleration chip (e.g. ADXL202,[16]) in a DR System.

By the following formula we can get the distance of walk by the acceleration :

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{s}}{dt^2}$$

[a=acceleration, v=velocity, t=time, s=distance]

$$\vec{v}(t) = \vec{v}_0 + \int_{x_0 = x(t_0)}^{x(t)} \vec{a}(t)dt$$

[velocity=initial velocity + acceleration*time]

$$\vec{s}(t) = \vec{s}_0 + \vec{v}_0(t - t_0) + \frac{\vec{a}}{2}(t - t_0)^2$$

[position = initial position + distance change]

Under the assumption of tracking a person over the period of 10 min and a noise of 0.01 g by the sensor we will receive a distance (error) of about x = ca. 17 km ! (e.g. a new world record). Regarding the error in the first step we can notice that this is less than 5%. Known systems are using acceleration sensors just as a pedometer. This technique is not very accurate in indoor areas or whenever the step length does vary. A human step takes in general about 1-3 Hertz and the speed of a foot is always set to zero when a step is done. The velocity of a foot at the starting and beginning is zero and so there are two points of reference. Under these circumstances it becomes possible to calculate the moving of a foot by acceleration sensors. Figure 6 shows a calculated walk distance by resetting the speed to zero at every step. After the last step the drift is visible. Cheap acceleration sensors doesn't compensate the earth gravity. When the sensor is mounted at the foot the co-ordinate plane is also moving relative to the ground.

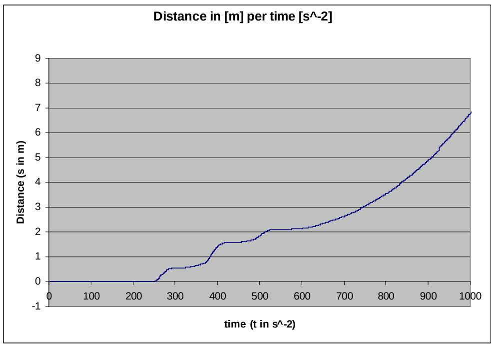

Figure 6: step length per time

For the angle α of the foot we have the acceleration in x and y direction

$$a_x = \cos(\alpha) \cdot a_x - \sin(\alpha) \cdot a_y$$

for the static gravity will get

$$a_{gy} = -\cos(\alpha) \cdot g \text{ and } a_{gx} = \sin(\alpha) \cdot g$$

Using a standard PDA we can calculate the acceleration in x direction of a foot by estimation function of the angle while walking.

For the application task of tracking the patrol of a security guard within a building it is possible to use e.g. beacons. These beacon can be infrared beacons which can reset the position of the tracking system. The error of the walk will be zero at the starting and endpoint and has it´s maxima on the half of the way. This also allows us to recalculate the relative length of the steps. Usually sensor signals are processed and transformed to situations in order to work on a situation aware mobile assistant. The mobile assistants are trying to archive the user`s goals. The assistant should act like a control circuit and check the results of the processing with the original goals. To observe the conditions of the system it can be necessary to increase the sensibility of the sensors

Figure 7: Infrared beacon

6 Applications

The Fraunhofer Institute of Computer Graphics Rostock developed a personal guide (eGuide) on the platform of PDA's, (personal digital assistant) to assist the user to navigate on exhibitions, museum and congresses. The location of the exhibit or other points of interest can be shown on a graphical map by a blinking cursor. The own location is known by infrared beacon and with a routing routine the best path between present location and the goal can be displayed. When a beacon is mounted at a conference room, further features are possible. By processing conditions like time, user preferences and location, the eGuide application is able to "see" what lecture is going on behind closed doors, or can give detailed information about the present position. By higher resolution of the current position we archive detailed knowledge about the users environment. The more we know about the situation of the user the better a digital assistant can support the user to obtain his personal goals.

Figure 8: Position tracking on a Palm Computer

Other Institutes are developing applications to support animal husbandry. By electronic pedometer is becomes true to increase the recognition of the rut and heat of cows as well as Mastitis because the moving activity is multiple heighten during that time. The pedometer are combined with the animal identification and are mounted at the feet. During the melk the data of activity are transferred to a server. By the graphical data the heat-period can be seen and the optimal time for the fertilization can be found. This method is known as the Fullwood technique[17].

But not only for animals it can be interesting to interpret sensor data like steps of pedometers. Medicine researchers found out that diabetics averaged about 1/2 the amount of walking that similarly-aged non-diabetics may average and concluded that 80% of the diabetics in their study could be properly classified as sedentary. The researchers used the threshold of ca. 8000 steps a day as the threshold for sedentarism (this is the 25th percentile of steps/day among nondiabetics). They note that similarly aged non-diabetics in a sample might average around 14000 steps/day[18].

Pedometer are not the single possibility to track the movements of the humans. In sleep laboratories the various movements of a sleeping persons are tracked. Medicines doing a tracking of the motion of the back in order prevent back-ache.
A possible application field is the tracking of the arm motion for assembling works. A blind could be lead to different objects, workers can build up a construction not only by a drawn plan but also by a guiding of the body.
Maybe in future we can buy suits with an integrated extensometer. We would be able to know our pulse rate and blood pressure and maybe we can track our walk by the angel and the movements of the legs. That technique would even work for astronauts.

7 Future Works

The implementation of a user tracking system on a personal digital computer (PDA) has to be close to the hardware. To be compatible to various hardware the used software code is written in Java. We could figure out, that the PDA´s with a Java Virtual Machine (KVM) is running about a hundred times slower than in native C Code. To improve the sensor input rate the future work will be to implement the FPGA technology and to use algorithm for the jumping problem and digital magnetic offset maps. Another challenge of research is the personal task management of the user. Situation aware systems will be an important field. Nowadays location based services are dealing with the question where the users might be, tomorrow they know why they are there.

8 Conclusions

Ubiquitous computing can support and observe us constantly for years and 24 hour per day. This circumstances can lead to a new kind of human computer interaction. Because of the permanent tracking of the user´s action it becomes possible that mobile assistants can provide information about the user in a very special kind. By our moving habits it can tell if we are ill or can give advises like - if we wouldn't do any jogging at the weekend, we will have a heard disease in 20 years. By sensorfusion computers will notice more about the environment and filters redundant information. More detailed situations are available by the right interpretation of the sensor signals which helps the context aware mobile computing to assist the user.

References

[1] Bieber G, A New Generation of Personal Navigation System for Fairs and Exhibitions, Workshop at the International NAISO Congress on Information Science Innovations (ISI'2001), Dubai, U.A.E., March 2001

[2] AUMA - Association of the German Trade Fair Industry, capacity of fair locations, 2000, www.auma.de

[3] Wehner R., Ant navigation: mini brains - mega tasks - smart solutions, Workshop at the International NAISO Congress on Information Science Innovations (ISI'2001), Dubai, U.A.E., March 2001

[4] Point Research Corporation, DRM U.S. Patent #5,583,776, 17150 Newhope Street, Suite 709, Fountain Valley, California 92708, USA.

[5] InterSense Corporation, 73 Second Avenue Burlington, MA 01803, USA

[6] Harter, Hopper, A Distributed Location System for the Active Office, IEEE Network, Vol. 8, No. 1, USA, 01/1994

[7] Butz, Baus, Krueger, Lohse. A hybrid indoor navigation system. In IUI2001: International Conference on Intelligent User Interfaces, New York, 2001. ACM.

[8] Röfer, T. (1995). Bildbasierte Navigation mit eindimensionalen 360°-Bildern. In: Dillmann, R., Rembold, U., Lüth, T. (Eds.): Autonome Mobile Systeme 1995. Springer. 193-202.

[9] Ide R. You are here, CG topics, Vol 12/2000, Darmstadt, Germany.

[10]Militarily Critical Technologies, Part III: Developing critical Technologies, Section 16A: Positioning, Navigation and Time Technology, Oct 1999 (updated May 2000), Defense Threat Reduction Agency, Dulles, VA

[11]Weiser M. Some Computer Science Problems in Ubiquitous Computing. Communication of the ACM 36, 12, 75-85.

[12]Schilit W.N., A System Architecture for Context-Aware Mobile Computing, Ph.D. Thesis, Columbia University, New York, 1995

[13]John B., Kieras D., The GOMS Family of Analysis Techniques: Tools for Design and Evaluation, Carnegie Mellon University, Human-Computer Interaction Institute Technical Report, Pittsburgh PA, 1994.

[14]Kirste, T. Mobile Information System for the Management of Networks. Proc. 24th IEEE IECON, Aachen, Germany, Oct 1998.

[15]Anderson F., Pandy M. , Dynamic Simulations of human motion in three dimensions, Proceedings of the Sixth International Symposium on the 3D Analysis of Human Movement, May 2000, Vineyard Hotel, Cape Town, South Africa

[16]Analog Devices Corporate Headquarters One Technology Way P. O. Box 9106 Norwood, MA 02062-9106

[17]Wendl G, Klindtworth, Yangey, Rechnergestützte Brunsterkennung mit Aktivitätssensoren in der Milchviehhaltung. Technische Universität München-Weihenstephan, 1995.

[18]Australian Center for Diabetes Strategies, Prince of Wales Hospital, Sydney, for the Diabetes Australia Guideline Development Consortium, National Evidence Based Guidelines for the Management of Type 2 Diabetes Mellitus, Sydney, Australia,, 2000