Location by solar cells: an experiment plan

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Abstract

Present indoor navigation techniques are relatively costly and little widespread. We believe that solar cells might be able to provide a partial solution by minimising hardware investment, providing useful *data* about the user environment and acting as an energy harvesting *power* source. In this paper the related state of the art is briefly reviewed, a vision of the implementable systems is provided, hypotheses with regard the use of solar cells as location aids are developed and planned experimentation is described.
We conclude that obtaining both "*power and data*" would be a novel use of an energy harvesting technology in the wearable computing domain. Such a combination would support the case that other energy harvesting technologies could also be used for providing energy and data. Applications can also be forseen beyond wearable computing.

State of the art

Indoor location can be achieved with a variety of technologies. These in the area of wearable computing include, but are not limited to:

- ultrasound (e.g. AT&T Laboratories BAT, MIT Cricket),
- radio frequency (e.g. WLAN: Microsoft Research RADAR, RFID: University of Washington SpotON, mobile telephone triangulation),
- infra-red (e.g. AT&T Laboratories Active Badge),
- (CCD) camera (MIT Patrol: Starner et al.).

Combinations of the above technologies such as radio frequency and ultrasound have also been studied (e.g. University of Bristol Low Cost Indoor Positioning System, University of Tokyo DOLPHIN: Fukuju et al.).
Details of all the above technologies can be found using a standard internet search tool such as Google, so for this reason and due to the limited pages of this document, no references to particular publications are provided.
Position has also been measured with lateral effect photodiodes (LEP) for example in robotics [1] and automated vehicles as well as with photodiode arrays in the case of atomic force microscopy [2]. However, both the latter required either a point source light (laser beam) or lens focusing of the light onto the LEP as in [3]. Narrow light beams are atypical indoors.
There are other technologies that are usually used as a complement to the location technologies already mentioned such as accelerometers, magnetic sensors (compass) and gyroscopic sensors [4].

Vision of system that is proposed

None of the above approaches to location explicitly use overhead lighting as the principal location reference. However a number of environments such as office corridors and manufacturing plants are lit for the majority of the day by fixed electrical light sources.

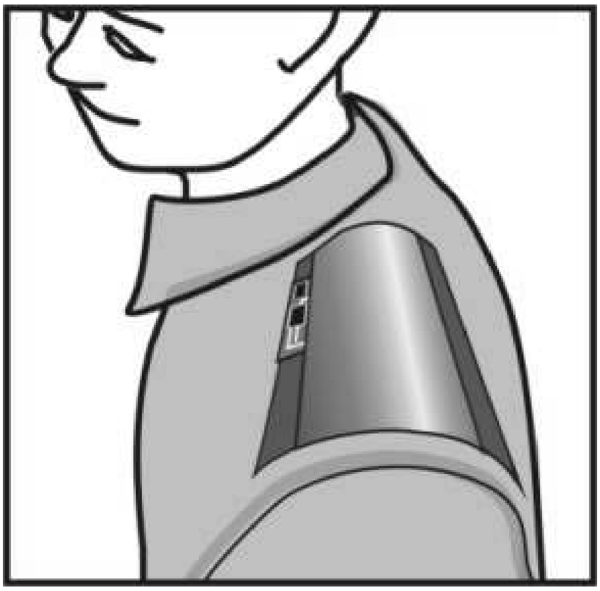

Figure 1: Solar cell location epaulette concept

A location tracking device based on existing technologies might look like Figure 1. The main components are a flexible solar module, a peak current detector and a pulse RF communication device. Not shown in Figure 1 is the RF receiver for the collected data that might be on-body or in the environment.
It is an important hypothesis of this project that shoulder mounted solar cells satisfactorily detect indoor lights. The level of accuracy would need to be sufficient for certain applications. If this were to be the case a number of advantages, all of which are adapted to wearable computing, would include:

- solar photovoltaic modules are relatively cheap sensing devices (around 1US dollar/module)
- as the modules are cheap, it may be feasible to have a number of them for each user in order to improve detection and location accuracy
- the modules deliver a relatively low data rate compared with other systems such as CCD camera; this suggests that wireless communication of the data would be low power
- solar modules can be prepared in thin films that would be very low weight and flexible (i.e. can be integrated into clothing)
- with sufficient surface, the solar module might provide power to location tracking devices or for other on-body computing purposes
- people wear a number of garments that cannot necessarily be electrically connected; the "power and data" concept may support wearable autonomous wireless sensor node solutions

Furthermore, research is already in progress on photovoltaic fibres [5]. These might be woven into fabrics thus allowing effective solar modules to be better integrated into clothing.
Conversion of the light detection data into usable location or navigational information generally requires one or more algorithms. Research in this area, both in robotics and ubiquitous computing, often apply Bayesian techniques that include Kalman filters, Hidden Markov models (HMM), dynamic Bayes nets and particle filters. It is proposed in an initial experiment in a hallway with regularly positioned fluorescent tubes that the periodic intensity variation detected from walking under the tubes be used to determine movement and walking speed. Simple time warping for template matching can be used to recognize the light intensity pattern curve. A HMM can then be developed and tested to associate the intensity peak of each sensor to a state probability. Assuming a large training database can be used, the classifier will be more robust against feature variations than the time warping approach that relies on a single sample model.

Hypotheses

Location and activity tracking

The basic requirement of each solar (photovoltaic) module is to "recognize" light sources. Detection is expected to be dependent on light type, size, height and position; the resulting accuracy should be comparable to a CCD camera with the advantage of reduced resources. It should also be possible to automatically distinguish daylight and fluorescent light by frequency and intensity. Changes in the ambient lighting will indicate user activity.
It is expected that the light levels experienced by a user moving down a corridor can be modeled and the models validated by the experiments mentioned in the next section.
It is hypothesized that increasing the number of solar modules per shoulder will allow more detailed information to be collected. For example, two solar modules on the same shoulder oriented in the axis of walking may be used to determine speed of movement. With three or more photovoltaic modules positioned equidistant from one another on the shoulder, it is hypothesized that orientation detection will be possible.
Provided the above basic data and a suitable algorithm implementation, it is proposed that location accuracy can be improved by using complementary devices. Such devices may include, but are not limited to, on-body sensors (e.g. step counter) and off-body devices (e.g. beacons or via fluorescent tube broadcast [6]). Location accuracy could also be improved with complementary information such as a map of the light sources (daylight and electrical) in a building, typical usage patterns of the lights and typical habits of the user(s) using the location devices. Finally, it would be convenient if the location system could learn from mistakes.

Energy harvesting (or towards an autonomous sensor)

We estimate that 0.7mW power can be collected from $80cm^2$ of active photovoltaic area positioned on an adult shoulder with a corridor fluorescent tube directly overhead. It is expected that sufficient average power is available to run a low power microprocessor that is able to handle signal conditioning, filtering, artifact removal and simple feature extraction. If this is the case, then pulse RF communication should also be feasible. Having sufficient average power for these functions implies a design trade-off between maximizing energy collected (i.e. by having the solar modules in close proximity and in a horizontal plane) and maximizing the location data collected, typically be separating the solar modules which suggests they will not be oriented in a plane that is perpendicular to the incident light.

Proposed experiments

For reasons of limited space, this section does not cover all above mentioned hypotheses. The focus is how to design the experimental system, what initial tests should be carried out and how to validate the concept.

Build first experimental system

The first iteration of hardware will consist of three photovoltaic solar modules per shoulder of around 27cm^2 each that can be individually monitored for current at minimum 200Hz. These six modules should be calibrated before and after use. The modules should be easily fixed on the shoulder and have some flexibility in their exact location so that the influence of position on the shoulder may be investigated. We expect to use "Velcro" for this. The modules shall be wired to a data storage device (e.g. laptop) that should be carried by the user. A system will be required for effective collection, annotation and data base access of the photovoltaic module data-sets. These data-sets will be used to validate models of the user moving down a corridor for example. Whilst in general peak light intensity is expected under each tube, special cases should also be catered for such as an intensity peak created by super-position of two adjacent lights.

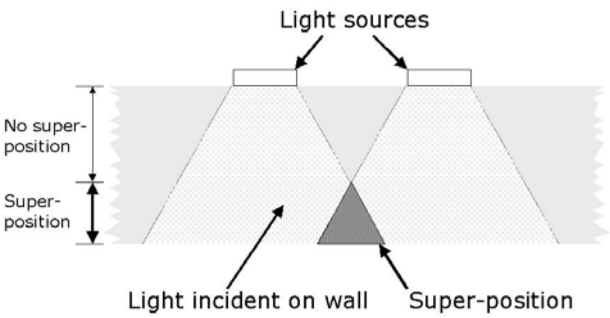

Figure 2: A special case: light source superposition

Initial experiments

Data will be collected for light intensity and frequency using the shoulder data collection system in various indoor environments, including near windows during daylight, under normal activity conditions. The shoulder system will also be used for testing a variety of individuals with characteristics representative of children, women and men performing everyday activities. Individuals should be tested who have long hair, wear hats and other related light obstacles to determine the related light detection deterioration and to determine the ideal location of the photovoltaic modules for each class of individual; potentially linear discriminant analysis will be useful for this. Data will also be collected for less normal activity such as swaying under a light or running back and forth near a light.

Based on these data-sets, algorithms will be developed that are able to locate an adult male walking at 1ms^{-1} down a predefined corridor within 1m using an off-line classification. For the corridor example, three algorithms based on different Bayesian approaches such as a HMM will be compared. The possibility of mixing algorithms to provide more accurate location data will be investigated, as well as the extent to which a map with skeleton data (walls and light positions) can improve location detection. The potential for complementary on-body sensors or off-body beacons to improve location accuracy will also be investigated.

All the above will lead to the building of a second iteration of the hardware based on what has been learnt through the experiments and using flexible solar modules.

Conclusion

A novel technique for low-cost location tracking has been proposed. It holds a number of advantages including the possibility of multi-functionality (sensing and a power source from the same device) and low cost. A number of hypotheses have been presented and initial experiments based on these have been described. The latter experiments are scheduled to take place at the Wearable Computing Lab. from November 2004 onwards; results are anticipated by February 2005.

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