# Indoor Tracking using Solar Cell Powered System: Interpolation of Irradiance

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## ABSTRACT

Indoor tracking, especially for wearable computing, often implies investing in infrastructure and/or the user carrying excessive volume and weight (e.g. WLAN enabled laptop). We make the hypothesis that existing infrastructure such as windows and fluorescent tubes may be used as primitive light beacons. On-body photovoltaic (solar) modules could be used as sensors. As a first step, we have interpolated indoor irradiance for an office environment and have confirmed that under these conditions, light sources may be identified. We conclude that our tracking concept should be further investigated. We propose hardware, how it operates and further work.

**Keywords**

Indoor Tracking, Ambient power, Solar cells

## INTRODUCTION

Various indoor location tracking systems are presented and compared in [1] and tracking algorithms for such systems has been reported from several research groups such as [2,3]. The applicability of the majority to indoor tracking systems is limited because they require electronic infrastructure that is not always available in buildings or needs installation. Indoor tracking of a person equipped with light and gyroscope sensors is a simpler approach. Take the example of a person walking down a corridor that is illuminated by fluorescent lights. The changing light intensity whenever the user passes under or near a light source can be measured. It was experimentally demonstrated in the WearNet project [4] that with simple sensors, activities such as entering an office room or an elevator, sitting close to a brighter place or in a conference room etc, can be tracked. In the system proposed in this paper, both wireless sensor device power and light sensing may be achieved with solar cells. The advantages are that the system could be smaller and batteryless. Data can be collected continuously and analyzed immediately or transmitted to a wearable computer such as QBIC (Wearable PDA like device) [5], which is integrated in to a belt. The system can track and support user navigation, such as 'you are taking a wrong turn'. It can also indicate to the user how far he or she is from a certain office room or predefined starting position.

## LIGHT SOURCE MODELLING

Two types of visible irradiance may characterize office environments: solar (daylight) and electrically sourced (e.g. fluorescent). Solar irradiance varies with respect to time of day, window orientation and is subject to rapid attenuation with distance from the window. As a result, electrical sources are the more dominant irradiance sources indoors. Our experiments have characterized indoor irradiance [6]. A significant number of measurements (1000s) in a typical room were made across ranges in all three dimensions; measures were also taken across a wide range of orientations with respect to the source, at 5 degree intervals. An interpolation was made in *Matlab*. The results of a typical office corridor are shown in Figure 1. The map clearly shows the 'islands' of increased radiant energy that coincide with overhead fluorescent lamps. We only interpolated the irradiance *in the corridors* for the current investigation.

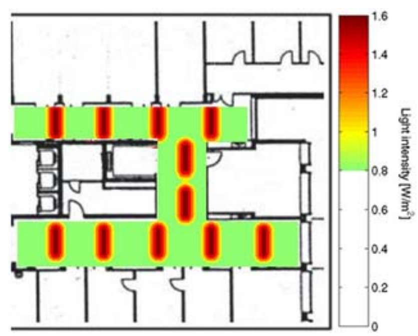


Figure 1. Interpolated radiant energy for typical office (only corridors)

From the measurements made, an irradiance in the range of 1-3 W/m$^2$ can be anticipated throughout the building on a standing adult's shoulders. Previously published results [7] have shown that in the range of irradiance of the present scenario, a conversion efficiency of 3% (-1/+0 %) can be expected from flexible solar modules. The proposed *'epaulette module'* made of amorphous silicon solar cells (which has a peak spectral response well matched to fluorescent tube light) can therefore deliver power in the range 20-90 mW/m$^2$ in an office environment lit by fluorescent lights. Given a photovoltaically active area of 100 cm$^2$ on each shoulder means that each module will continuously deliver 0.2 - 1 mW indoors. The 1 mW represents the power output when the shoulder is directly below the light source.

## TRACKING SYSTEM HARDWARE AND OPERATION

The hardware components of the proposed system are shown in Figure 2.

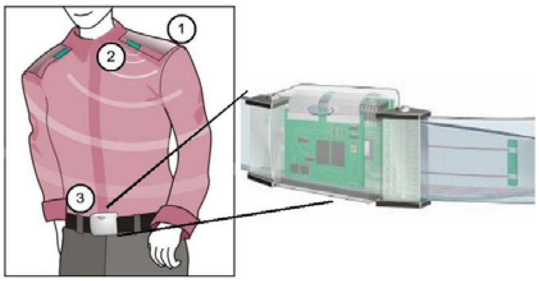


Figure 2: Tracking system hardware

1. Removable flexible *solar cells*, one on each shoulder ($100cm^2$ each), which act as light sensors and ambient energy harvesting devices.

2. *Peak current detector and Transmitter* - circuitry to detect abrupt current changes generated by the solar cells. The Control Circuit collects the inputs from the peak current detectors and decides when to transmit a pulse to QBIC. An optional *Super-capacitor* acts as a stable power supply for the sensor circuitry and a storage device for excess energy harvested form the solar cells. The power requirement for the circuitry (including the pulse generator and transmitter) would be less than 1mW during operation and few μW during standby. Therefore, the proposed implementation can be powered by the energy harvested from the solar cells.

3. The *QBIC* (Belt worn - wearable computer) - holds a complete electronic map of the lights of the office floor and runs the tracking algorithm. A *Gyroscope* is integrated into the QBIC records users relative direction (angular displacement) of walking.

By combining information from the peak current detector, the gyroscope and an accurate electronic map of lights in the floor (stored in QBIC), the user's location can be determined with a reasonable degree (range of 1-2m) of accuracy with a tracking algorithm. This algorithm keeps tracks of the user in incremental steps (relative to a known starting point) based on the sensor information.

Opportunities for further development of the system include, but are not limited to:

- Photovoltaic fibers can be used (a woven solar cell) instead of flexible solar cells for user comfort.
- There could be many floors in the same building with the similar light pattern. In such a case, an atmospheric pressure sensor can be used to determine on which floor the user is [4].
- Applying a probabilistic algorithm to compensate for missed or switched off lights. This could predict, based the users previous movement, their location and direction.
- Ensuring that the tracking system can (re-) synchronize correctly, either via the shoulder mounted sensor (e.g. using special frequency signature lighting) or via the QBIC using existing wireless beacons or visual markers.

## CONCLUSIONS AND FUTURE WORK

We have shown evidence supporting the case that indoor tracking using ambient power source is feasible from the following perspectives:

- Irradiance varies over a measurable range indoors
- This variance corresponds to irradiance sources whose location is fixed.
- Solar cells can be used as a sensor device as well as an ambient energy-harvesting device.
- Relatively simple electronic components and algorithms together with existing systems can be used to implement the proposed system.

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