Poster Abstract: LocaLight - A Battery-free Passive Localization System Using Visible Light

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***Abstract*—Most existing indoor localization systems are battery-powered and use the changes in Radio Frequency (RF) signals to localize objects. In this paper, we present LocaLight: a battery-free indoor localization system that localizes objects using visible light by tracking the shadow they cast. By sensing a drop in the intensity of ambient light caused by the presence of a shadow, LocaLight localizes the object. Since the position of the shadow can be predicted, it is possible to localize the object in a sensitive area by carefully positioning the light sensors and the overhead lights. Our initial results suggest that LocaLight achieves an accuracy comparable to many of the state-of-the art solutions that use RF.**

Fig. 1. **LocaLight Overview:** WISP computational RFID tags equipped with photo-diodes are placed on the floor under the illumination zone of the LEDs. These tags periodically wake up after harvesting sufficient energy from ambient RF signal generated by the RFID reader, sense ambient light to detect the presence of a shadow and communicate back to the reader if it is detected.

I. Introduction

Many applications such as assisted living, indoor and retail navigation need precise location information. Achieving high localization accuracy indoors by using Radio Frequency (RF) is particularly challenging owing to multi-path, fading and cross technology interference (CTI). Some existing solutions mitigate these effects by using multiple antennas [1], directional antennas [2] etc. These solutions, however, increase the deployment cost and complexity as they require specialized hardware or need to perform complex signal processing which increases power consumption. Using RF makes these systems prone to CTI from other wireless networks affecting the reliability and accuracy of some location systems [3].

Visible light is an alternative to RF for both communication and sensing. The highly directional nature of visible light makes it appealing for localization systems, as it can be bounded to specific physical spaces. Unlike RF, it is not significantly affected by multi-path reflections. Existing visible light based systems achieve sub-meter accuracy [4], comparable to state-of-art systems that use RF. However, all these systems are active in nature, i.e., users/objects being localized need to carry a sensor that receives the light beacons. This is a major limitation which increases the complexity and the cost of deployment of such systems.

A shadow is a region of reduced light intensity formed behind an opaque object whenever it blocks a source of light. In an indoor environments artificial lighting is almost omnipresent. As persons move in the presence of these lights their shadow follows. The precise location and the size of the shadow can be controlled by positioning the overhead lights. We precisely use this fact to localize passively. Existing attempts to use shadows for sensing are limited to inferring user gestures using large arrays of powered photodiodes [5].

In LocaLight, we place a fixed number of computational RFID sensor tags equipped with photodiodes at predetermined locations on the floor covering each illumination zone as shown in Figure 1. These sensors are powered by incident RF signals from a RFID reader making all the sensors battery-free. This overcomes a major limitation of existing visible-light based localization systems: batteries increase the dimensions, the cost of sensor nodes and maintenance costs for, e.g., exchanging batteries. Sensors without batteries can also be embedded in materials at the time of construction which enables new applications. Note, we only use the RF to power these sensors and to communicate in case a shadow is detected. These sensors, after harvesting sufficient energy, sample the on-board photodiode and communicate to the reader when a drop in the light intensity is detected. This makes LocaLight the first battery-free localization system that uses visible light for sensing, and passively localizes using shadows.

II. System Overview

Light-zone. A light bulb emits a beam of light that can be approximated to a cone. On the floor, the light forms a circular zone that we call "light-zone". The dimension of this zone depends on the bulb's location, height (h), and the beam angle (α), as shown in Figure 3. We divide our area of interest in such "light-zones". Depending on the location of the persons in a specific zone, their shadows fall at different locations. In LocaLight, we place the sensors at the boundaries of the "light-zone" at points 1 and 2 (see Figure 3). When a person of

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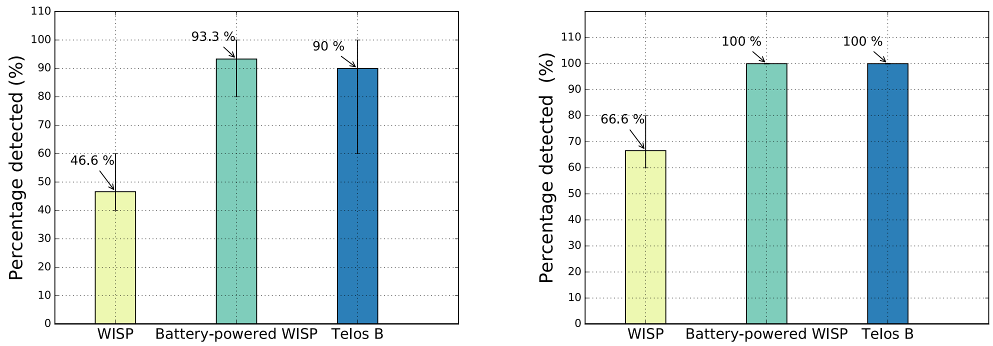

(a) Fast speed

(b) Slow speed

Fig. 2. We evaluate LocaLight by looking into the percentage of successful shadow detection with two different walking speeds using WISPs, battery-powered WISPs and Telos B nodes.

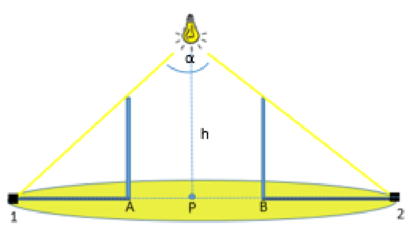

Fig. 3. **Light-zone :** Area of illumination under a single source of light. The point 1 and 2 are the indicative position of the sensors which can detect presence of person of up to position A and B respectively. h is the height of the bulb from the ground, and α is the beam-angle.

a given height stands at least at point A or B, their shadow will be correspondingly cast at point 1 or 2. Further, the position of the person can be predicted within a light-zone by using the property of similar triangles. This allows us to localize a person within the light-zone. Consider a bulb located at a height of 2.5 m, a person of height 1.75 m and a light-zone of radius 0.7 m: In this scenario, we can predict the location of the person up to 50 cm which is also the localization accuracy of the system.

Platform. As a sensor platform we use Wireless Identification and Sensing Platform (WISP) 5.0 [6]. WISP is a computational passive RFID platform with a MSP430FR5969 microcontroller. As opposed to passive RFID tags, the microcontroller makes WISPs application-agnostic. As compared to a more traditional sensor platform like the TelosB, WISPs use backscatter communication that is orders lower in energy cost than traditional RF. WISP runs on energy harvested of the incident RF signal making it battery-free. We equip the WISPs with photodiodes to detect the presence of shadows.

III. Evaluation

We set up a one-dimensional localization scenario with three LED bulbs and five sensor tags. We use the Impinj's Speedway Revolution R420 reader equipped with three 9dBi circularly polarized antennas as RFID reader. To evaluate the system we look into the number of nodes that properly detect a shadow when a person walks the straight line at two different speeds. The referred "slow speed" is obtained by walking the 4.5 meters distance in 14 seconds and the "fast speed" is obtained for the same path in 6 seconds. We repeat the experiment for 6 iterations as well as with battery-equipped WISPs and Telos B nodes. Figure 2 shows that the performance significantly improves when the WISPs are battery-powered. This indicates that the power harvested by the WISP 5.0 is not sufficient for a real-time positioning system. We are working to improve this. For a system without real-time requirements, however, the detection accuracy of the battery-free system is sufficient. The results show that the performance of the system with battery-equipped WISPs is comparable with Telos B. By using backscatter communication, the energy consumption of battery-powered WISPs is orders of magnitude lower than that of Telos B.

In summary, our results show that LocaLight is a battery-free localization system that achieves an accuracy comparable to many of the state-of-the-art solutions that use RF [7].

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