Demo: ShadowMaps, The Urban Phone Tracking System

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ABSTRACT

Due to frequent non-line-of-sight (NLOS) signal reception, geopositioning using Global Navigation Satellite Systems (GNSS), such as GPS, is unreliable in urban environments, with errors on the order of tens of meters. This poses a major problem for mobile services that benefit from accurate urban localization, such as navigation, geofencing, and hyperlocal advertising applications. Mobile network operators also seek improvements in localization, as government regulators increase handset location accuracy requirements of enhanced 991 service (e911). In our demonstration, we will present the most recent prototype of our urban location improvement technology, called ShadowMaps, which will be shown to accurately track a mobile device in an urban environment, with up to an order of magnitude reduction in GNSS positioning error.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous

Keywords

System Demonstration; GNSS; GPS; Localization Improvement; Crowdsourcing; 3D Mapping

1. INTRODUCTION

Many mobile services, including location-based advertising, navigation, and emergency response applications, benefit from or require accurate geolocalization outdoors. Another, more specific example is a so called "phone finder" app that allows a user to remotely track their device if it is lost or stolen via a web interface. Unfortunately, however, in dense urban environments accuracy of the often relied upon Global Positioning System (GPS) degrades significantly, with errors on the order of tens of meters [5].

The main culprit for this performance bottleneck is that in large cities the line-of-sight (LOS) to various satellites becomes occluded by buildings, leading to non-light-of-sight (NLOS) and multipath signal reception. As a result, the only satellites useful for accurate trilateration come from a narrow region in the sky, yielding poor satellite geometries and positioning accuracy, particularly in the cross street direction. The underlying geometry problem is not solved even as additional constellations of Global Navigation Satellite Systems (GNSS) – such as the Russian GLONASS – become supported by mobile devices. Fortunately, though, this urban "Shadowing Problem" can be exploited in two steps, as we have shown in previous research [1, 2, 4]. In our demonstration, we will showcase an end-to-end application of our previous research, the real-time phone tracking system called *ShadowMaps*.

### 1.1 Probabilistic 3D Mapping

The first step to exploiting the Shadowing Problem is to use crowdsourced satellite signal-to-noise ratio (SNR) measurements to create 3D maps of the environment. Intuitively, this is made feasible by the simple observation that, for example, the SNR of signals obstructed by buildings is lower on average than that of LOS signals. Reality, however, is more complicated: multipath fading can be severe in urban environments, leading to low SNR values even for LOS satellites. As a consequence, in cities single SNR measurements are generally unreliable indicators of whether a satellite is LOS or NLOS. To address this, in [1, 2] we proposed to use large amounts of GNSS data and to assign likelihoods of blockage to satellite-to-receiver "rays" in accordance with a wireless channel model. Afterwards, one can then "probabilistically stitch" many such rays together into 3D maps using machine learning techniques. If the necessary GNSS data is crowdsourced from many devices and cloud-based computation is leveraged, building such 3D maps can be done cheaply and scalably.

### 1.2 Real-time Positioning

The second step is to use a sort of reverse process to mapping, called Shadow Matching (SM). As illustrated in Figure 1, in SM 3D map databases and real-time satellite coordinates can be used to compute the shadows of buildings with respect to various satellites. Then, lower (or higher) satellite signal-to-noise ratio (SNR) measurements can be used to probabilistically match the device's location to areas inside (or outside) various shadows, reducing positioning uncertainty.
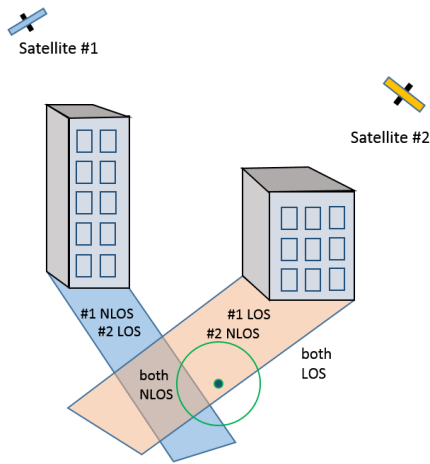
Figure 1: Illustration of positioning improvement using Shadow Matching.
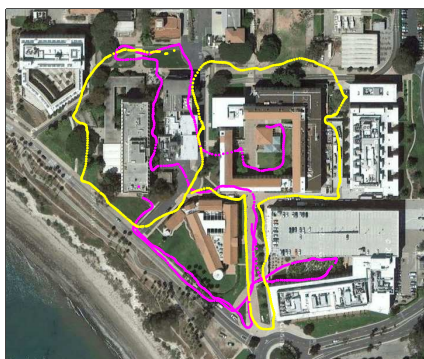
Figure 2: Google Maps aerial view of the portion of UCSB campus that was mapped in [1], with 2 out of a total of 34 input datasets shown for reference.
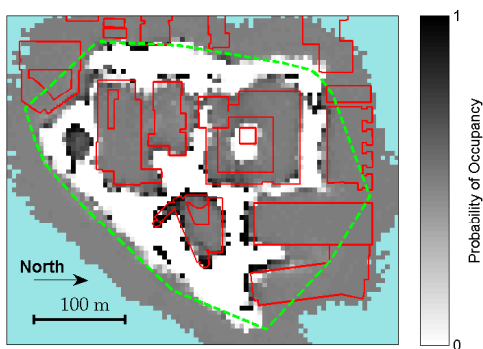
Figure 3: Example horizontal slice (5-10 m. above ground) of the resulting map. White/black areas correspond to low/high probability of occupancy, and building contours obtained from OpenStreetMap are shown in red.

Of course, in practice any useful SM algorithm must also enforce motion continuity for the device whose location is being tracked. In [4], we describe a simple particle filter that performs SM in addition

to considering such kinematic constraints, and which is also fully implementable in application level software. Showing how such a software-based SM filter functions in a real system will be the focus of our demonstration.

2. EXAMPLE EXPERIMENTAL RESULTS

At the time of the writing of this document, we have prototyped our mapping and positioning algorithms in downtown Santa Barbara and on the University of California, Santa Barbara (UCSB) campus. Although our offline mapping algorithms will not be the focus of our demonstration, some results of our UCSB mapping experiments are shown in Figures 2 and 3, which were created from about 7 hours of GPS data collected outdoors over several days using an Android tablet. The results from a separate downtown Santa Barbara experiment, where over 25 hours of data was logged using 4 Android devices, can be seen in Figures 4 and 5; in this experiment, 2D OpenStreetMap mapping data was used as a-priori information on the bottom two layers of the map.

Figure 4: Aerial view of downtown Santa Barbara, with GNSS traces in red and mapped region outlined in yellow.
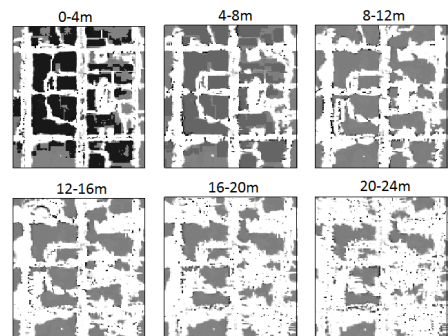
Figure 5: Horizontal layers of the generated occupancy map of downtown Santa Barbara.

Since having published [4], we have made significant progress with our localization algorithms. Specifically, we have improved the performance of our particle filter, which we have successfully prototyped both on campus at UCSB (as shown in Figure 6) and in downtown Santa Barbara (see Figure 7 and our YouTube video [3]).

3. SYSTEM DEMONSTRATION DETAILS

In our demonstration we will remotely and accurately track an Android device traversing an urban environment that we will have previously mapped (for example Santa Barbara – an area we have already mapped – or alternatively San Francisco, a portion of which we plan to map this summer). Our Android phone finder app,
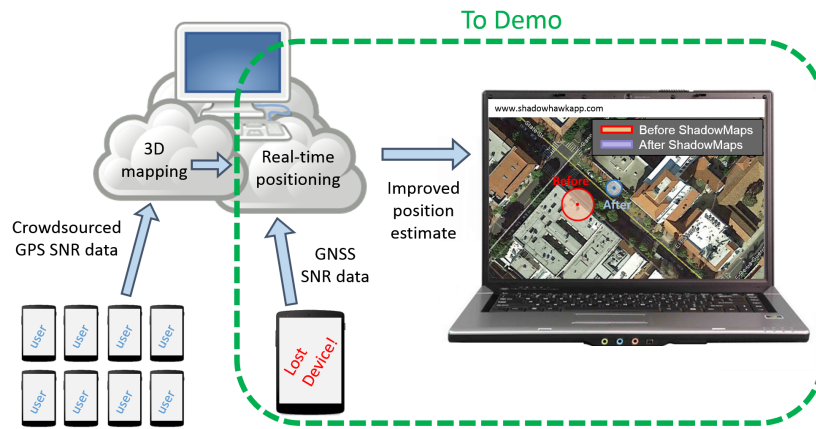
Figure 8: ShadowMaps system architecture and the components comprising the demonstration.
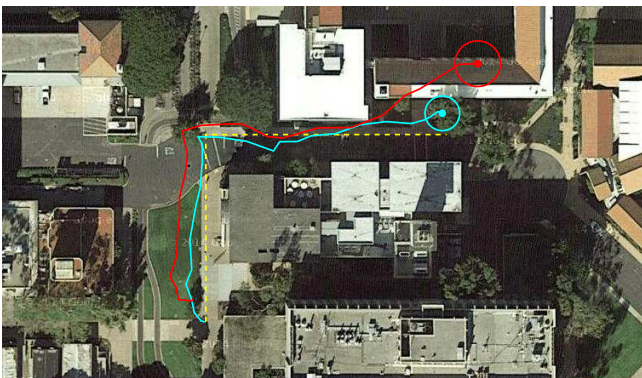

Figure 6: Positioning improvement at UCSB: true path in yellow, standalone GNSS output in red, and corrected (post-SM) path in light blue.
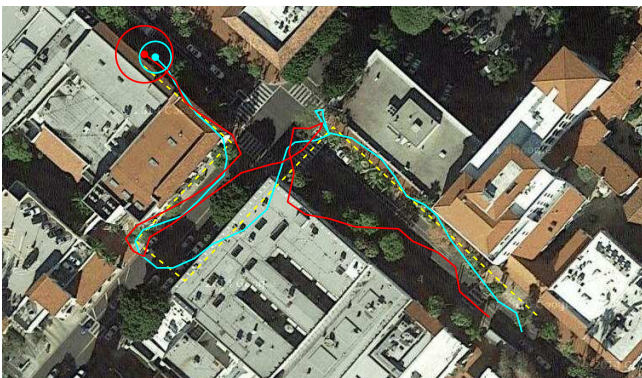

Figure 7: Positioning improvement in downtown Santa Barbara: true path in yellow, a-GNSS output in red, and corrected (post-SM) path in light blue.

called ShadowHawk, runs as a background service on the device, passively providing satellite SNR data to our servers, as well as some ancillary information (GNSS latitude-longitude fix, uncertainty, etc.). There, our real-time positioning routines compute and store revised position fixes. These improved position estimates can be viewed through a map-based web interface, which displays the current location and past locations of the tracked device. The web interface will be displayed on a laptop on site at MobiCom. This is the main user interface (UI) for ShadowHawk. As a means of verifying ground truth, our demo will also include a live video feed of the user who is being tracked (one of the authors) walking in the area of interest. A schematic of the ShadowMaps system which highlights the portions we will demonstrate is shown in Figure 8.

3.1 Facilities and equipment needed

We will need power plugs for a laptop and a TV monitor to display our tracking results. Additionally, we will need a table large enough to fit these items and a reliable internet connection (preferably wired) for the real-time demonstration. Setup time should be at most half an hour.

4. REFERENCES

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