Research Statement

“Mobile/Wearable Analytics for Urban Sensing & Services”
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Overview
My research interest can be summarized as:

“the use of sensor data from mobile phones & wearable devices for understanding individual and collective human behavior during commonplace daily lifestyle activities (e.g., shopping, eating or studying on a college campus), and applying such real-time and predictive insights to the development of new urban sensing paradigms and services”.

Within this broader theme, my research interests and accomplishments can be organized around three technical themes (illustrated in the figure on the next page):

A) Mobile & Wearable-based Sensing & Analytics: This research thread focuses on the judicious use of smartphones and wearable sensors, in combination with emerging infrastructure-based (IoT) sensors, to derive an understanding of the “what, where, when and why” people do, as part of their daily lifestyles. Over the last year, my interests in this space have especially migrated to (i) studying the new opportunities that wearable devices, such as smartwatches, provide in capturing activity and gesture recognition, and (ii) using the aggregated observation of such activities by multiple individuals to infer the “status of resources in urban spaces”—such as the queuing delays in a food court.

B) Mobility-Based Urban Services: The focus here is on exploiting the collective patterns of urban mobility and behavior to explore new urban services. My specific primary interest relates to the theme of “urban mobile crowdsourcing”, where the mobility patterns of a large body of individuals is leveraged upon to perform a variety of location-specific tasks (e.g., checking on the cleanliness of a restroom or delivering a package), either in campus environments or at city-scale.

C) Socio-physical Analytics: This is an evolving and exciting direction of research that looks to combine the insights on physical behavior (gathered via the techniques of theme “A” above) with analytics of content and interactions on social media channels (such as Twitter and Instagram). Concretely, my current interests are in (a) analyzing different social sensing feeds (e.g., Instagram images and Twitter feeds) jointly to detect and characterize events, and thus enhance urban situational understanding and (b) combining mobility data (e.g., from cellular traces in a city or Wi-Fi traces on a campus) with such social media content to provide early detection of anomalous or unexpected events.

Broadly speaking, all of my work aligns with SMU’s “Analytics for Business, Consumer and Social Insights” area of excellence, and hinges on the emergence of mobile & wearable devices as providers of deep digital traces about individual activities, as well as the spontaneous sharing of multimedia content on various events by urban inhabitants.
My research efforts also contribute to two major research centers in SMU:

- The **LiveLabs Urban Lifestyle Innovation Platform** ([LiveLabs](http://www.livelabs.smu.edu.sg)), is a testbed-oriented research effort that focuses on (a) extracting advanced behavioral context from the personal mobile devices of consumers in urban venues (including the SMU campus, an airport and a convention center), and then (b) enabling experimental testing of context-aware consumer engagement strategies. See [Jayarajah:16][Misra:13] for a deeper understanding of the capability of LiveLabs.

- The **Living Analytics Research Center (LARC)** ([http://www.larc.smu.edu.sg](http://www.larc.smu.edu.sg)) is an interdisciplinary research effort that seeks to develop technologies for societal-scale analytics and closed-loop experimentation in both online and offline domains, and includes efforts specifically related to socio-physical analytics and urban mobile crowdsourcing.

**Research Areas**

Here is a more categorical and detailed enumeration of my research areas and activities.

**A. Mobile & Wearable Sensing & Analytics**

My work in this area can be organized under 2 sub-categories.

- **Mobile Sensing & Analytics:** This body of work looks at collecting individual mobile and wearable sensor data in real-time and applying analytics on such data to infer the individual and collective activities in public spaces. This work is conducted as part of the LiveLabs and LARC research centers, and addresses the technical challenge of collecting important sensor data fast (low latency), while keeping the energy overheads low.
One example of such real-world mobile sensing-driven is “queue detection” in places such as shops, food courts and taxi stands—our QueueVadis system [Okoshi:14] first applies feature-based classification techniques on individual smartphone’s accelerometer streams to infer the person’s locomotion patterns and thus determines if he/she is currently queuing. A backend analytics service then applies spatiotemporal signal processing techniques on these individual outputs from participatory users to determine a) if there is indeed a queue, and b) if so, the service and wait times associated with an individual queue, thereby enabling up-to-date estimates of wait times at food courts, coffee shops etc.

Another example of such analytics is “group detection”, which seeks to identify the distinct group-based interactions among tens of thousands of people visiting crowded urban spaces (e.g., a shopping mall). In past work [Sen:14], we described the design, development and on-campus deployment of GruMon, which supports real-time detection of groups by fusing the spatiotemporal trajectory data with other mobile sensor data (e.g., accelerometer and compass streams). We have since used such underlying group analytics to demonstrate that (a) the mobility and place transition patterns differs significantly between individuals and groups [Misra:14], and (b) such group context is vitally important to predict not just mobility, but other aspects of human behavior, such as an individual’s interruptibility and mobile App usage [Jayarajah:15a].

• Wearable Sensing of Lifestyle Activities: Over the past year, I have increasingly focused on understanding how the new crop of commercial wearable devices (e.g., the smartwatch) can help capture accurate understanding of finer-grained human activities and gestures, during regular lifestyle activities.

One example of such activity recognition is ongoing work on building an automated “Eating Detection and Food Journaling” system called Annapurna [http://is.gd/annapurna]. In this effort (initial results in [Sen:15]), we assume that the user has a wrist-worn smartwatch. The inertial sensors on the smartwatch first determine the time periods when the user is eating; the system subsequently intelligently triggers the smartwatch camera to capture images of the food being consumed. Finally, the backend Annapurna portal selects only the best images corresponding to the food consumed, and then publishes them via a personal portal. This automated food journaling system can be useful for applications in diet and health monitoring, as well as generating automated alerts when unhealthy eating habits are detected (e.g., if a college student skips breakfast).

Another such example of wearable-based lifestyle analytics is Shopping Analytics—i.e., the capture and understanding of a shopper’s in-store gestural interactions with products. The goal is infer the shopper’s preferences and interests from these exhibited physical shopping-related actions within a store. One early example of such analytics is the IRIS platform [Radhakrishnan:16b], which uses a combination of smartphone and smartwatch sensor data (without any infrastructural support from the store) to first infer a shopper’s micro-gestural activities (such as “picking up an item” or “placing it in a shopping cart”), and then applies analytics on the pattern of such gestures to infer a shopper’s higher-level attributes (e.g., “shopper is in a hurry”). Similarly, building upon earlier work in infrastructure-augmented gesture detection [Subbaraju:15], we are developing an IoT+wearable sensing framework, which combines multiple low-energy BLE beacons, mounted on store shelves, with smartwatch sensing to further identify the specific items that a shopper has browsed (see [Radhakrishnan:16a] for preliminary work). The challenge in such scenarios is to both locate transient changes in a hand’s position (as shopping gestures often last less than 1-2
secs) and to conserve the BLE interface on the wearable (as our studies [Radhakrishnan:15] showed that the energy overheads of continuous BLE scanning on a mobile device is prohibitive).

B. Mobility-Based Urban Services
Over the last two years, I have become increasingly interested in the inter-disciplinary field of “urban mobility”—especially, in understanding how predictions of user movement can be combined with advances in scheduling and decision optimization to create improved applications of “mobile crowdsourcing”. My current work can be broadly categorized into two areas:

- **Resource-Tracking for Mobile Crowd-tasking**: I am looking at ways to provide better task recommendations and pricing structures for using mobile workers to crowdsource the collection of reports on the condition of various urban resources (e.g., the cleanliness of restrooms on a college campus or the amount of residual space in a housing estate’s garbage bin). In collaboration with Xerox Research, we have developed the paradigm of “coordinated predictive task recommendation”, where tasks are proactively recommended to individuals in a way that imposes minimum deviations from their predicted travel path, while ensuring that the task assignment/recommendation process satisfies other constraints specified by task owners. We showed [Cen:14] that such recommendations can lead to higher task completion rates with lower detours, even when we consider [Cen:15] the probabilistic uncertainty in the future travel routes of individual workers.

We have applied these results to build and deploy Ta$ker, a mobile crowdsourcing application on our SMU campus, that is used to crowdsource reports on campus resources (e.g., the residual space in garbage bins or the stock availability in a vending machine) from volunteering students. Ta$ker uses trajectory analytics over Wi-Fi based location tracking data to recommend such tasks to student volunteers, and also allows us to experimentally test the impact of various crowdsourcing features (e.g., task bundling or variable task pricing) on real users. Ta$ker has been deployed [Kandappu:16] on the SMU campus, to enable a “smart campus” vision of real-time resource awareness. In future, I plan to work to extend these mobile crowdsourcing technologies for city-wide monitoring of municipal resources.

- **Resource-Tracking for Mobile Crowd-tasking**: In this work, we are partnering with a dynamic Singapore-based SME (small-medium enterprise), to explore the new paradigm of **crowd-logistics**, where crowd-workers are used to deliver packages between (source, destination) endpoints. This problem is a more complex variant of the original mobile crowd-tasking problem, as detours now involve both source and end destinations associated with each package. In recent work, we have developed a “task bundling” approach that factors in *aggregate* worker movement patterns (e.g., obtained from analysis of public transport data traces) to develop task bundles that are more likely to be selected by workers, and that are expected to minimize the worker’s delivery-related detour overhead. In future work, we plan to develop joint bundling-recommendation strategies that create specific delivery bundles for each specific worker, and test the efficacy of our technologies using our logistics partner.

C. Socio-Physical Analytics for Urban Sensing
The research efforts on this theme can be broadly classified into two areas (and is carried out primarily at the LARC center, with partial funding support from US AOARD/ARL agencies):

- **Multi-modal Social Sensing for Urban Event Detection**: In this area of work, my goal is to utilize content posted on social media channels (e.g., Twitter, Instagram) to detect urban
events, by applying information-processing tools on both the metadata (e.g., the location tag of an Instagram post, or the total number of Tweets with a specific hashtag) and the data/content (e.g., identification of the objects in an Instagram image). Specific problems of interest include the ability to identify distinct micro-events (e.g., that 2 different bands are playing on 2 different stages at a music festival), perform fine-grained event localization (e.g., isolate each band event to a specific street corner) and establish the veracity/credibility of such events. In contrast to the vast body of work on semantic social network analysis (that employs techniques such as text mining), my goal is to apply and adapt signal processing tools previously utilized in physical sensor networks to this problem. Early examples of this approach include [Jayarajah:15c], which defined the overall processing pipeline for a real-time situational understanding framework, and [Dai:16], which showed how Instagram metadata and data could be used to understand the spatial distribution and society-level behavioral impact of the Haze event in Singapore in 2015. In ongoing work, we are looking at jointly analyze statistical properties of Image images and labels to identify the spatiotemporal evolution of micro-events at sporting events (e.g., different marathons).

- **Anomaly and Event Detection in Public Spaces:** This work tries to discover unexpected events in public venues (e.g., college campus, performance arts center), based on the individual and collective patterns of movement and behavior at these locations. The key challenge is to discover the combination of discriminatory socio-physical features that best identify such anomalies and events. In initial work [Nayak:15], we have shown how a variety of features (such as occupancy levels, or rate of change of occupancy) can be combined with Markovian models to capture events that result in large-scale or rapid changes in human occupancy (e.g., fire drills or student fairs on our campus). More interestingly, we have then shown how social features [Jayarajah:15b] (e.g., the tie-strength among individuals inhabiting or transiting a space) help us to discover smaller-scale events (e.g., an ice-cream social) as well. In ongoing work, we are enhancing such event detection analytics to additionally (a) use individual movement-based (i.e., location transition-driven) features and (b) combine such mobile sensing-based insights with video analytics (obtained from surveillance cameras typically deployed at a few sporadic locations).

At a high-level, all of my recent and planned future work revolves around the vision of a “smart city”, where challenging problems related to various urban services are addressed by a judicious combination of IoT (sensor devices) and human-carried wearable and mobile devices. Moreover, I believe that such a combination of sensing and analytics offers unprecedented opportunities to develop measurable indices of collective human wellness and “urban livability”, with deep benefits for social sciences and urban planning.

**Selected Publications**


