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Fusing Social Media and Mobile Analytics for Urban Sense-Making

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Fusing Social Media and Mobile Analytics for Urban Sense-Making

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Abstract:
The project was motivated by the observation that urban environments are increasingly characterized by a variety of non-traditional “sensors”, whose data streams can be harnessed to infer a variety of latent events and urban context. For example, users spontaneously generate huge amounts of content (text, images and video) on social network channels, whereas GPS & other sensors on taxis and buses increasingly provide near-real time traces of their movement throughout the city. Similarly, advances in Wi-Fi based sensing allow us to passively capture the individual and collective movement of visitors across various public spaces, such as college campuses, museums and convention centers. The goal was to develop analytics algorithms and techniques to fuse the information from these diverse sources, to more accurately characterize urban events, both at city-scale (such as sports activities, and protests) and within specific campuses (such as university events). Through our work, we have developed a variety of novel algorithms for fusing such non-traditional sensor data. Our work has included (i) the use of Wi-Fi sensing data, optionally coupled with video monitoring, to detect events; (ii) the use of social-media and/or city transportation data to detect where and when events happended and (iii) the development of new crowdsourcing techniques that help increase the participate rate of city residents in reporting on such events. Our results and techniques provide foundational capabilities in the area of urban event sensing and anomaly detection.

A. Introduction

The research aimed to develop analytics techniques that fuse insights from

1. sensing of physical world behavior (e.g., the indoor movement or group interactions of people, or the location and crowdedness of buses and taxis), with
2. sensing & digital traces of online behavior (e.g., calendar entries of individuals, campus events registered in online portals or social media content generated by applications such as Twitter and Instagram).

These research investigations were made possible by the availability of both online and physical world data from (i) SMU’s unique, large-scale mobile sensing testbed, called LiveLabs, that provides longitudinal observations of the daily lifestyle behavior of several thousand students, both on and off campus; (ii) SMU’s capture of extensive traces of online social media data via its large-scale real-time crawling of content on public social media channels; and (iii) Singapore’s public agency-driven information portals that provide a variety of real-time urban data feeds to aid “Smart Nation” initiatives. Our research helped usher in a new field of analytics that we call Socio-physical analytics (we are one of the first proponents of this field), that provides invaluable insights into events and anomalies in urban environments.

Our work has resulted in the development and validation of novel algorithms for such urban-scale multimodal sensor fusion. In addition to such novel algorithmic breakthroughs, our work had a systems-driven initiative to build working prototypes and pilots, and have resulted in at least 3 distinct analytics-driven urban portals and applications. At a high-level, our algorithmic and systems-oriented research initiatives have resulted in 4 distinct activities and tasks:

1. Event Detection in Urban Public Spaces: This work has focused on the ability to look at longitudinal traces of individual and group movement data (both within a university campus and across an entire city), and utilize features on such movement traces to identify unusual events at various urban locations.

2. Coordinated Urban Mobile Crowdsourcing: This work has looked at both spatiotemporal optimization algorithms and empirically-determined behavioral incentives that allow the real-world deployment of mobile crowdsourcing services. In such deployments, a time-varying pool of workers perform various location-specific reporting tasks and thereby provide a practical way to infer the occurrence of events and the state of resources, both in a smart university campus and across an entire city.

3. Multi-modal Social Media Sensing & Urban Profiling: This task has developed new techniques by which user-generated social media data, expressed via different modalities and using different applications (e.g., image posts on Instagram vs. text content on Twitter), can be combined to parametrize various urban phenomena. In particular, we applied our techniques to quantify the intensity of Haze (a periodic large-scale urban pollution event in Singapore) and to identify micro-events during various Marathons.

4. Socio-Physical Sensing for Urban Events: This is the newest of the four tasks. This task looks at how attributes of various physical-world urban resources (e.g., the locations and occupancy levels of buses or the road congestion levels captured by traffic cameras) can be used to identify and localize (in both space and time) both large and small-scale urban events.

Our work has resulted in 12 publications at high-quality, international refereed conference venues, and 9 invited/keynote speeches at well-recognized conference venues.

All of these investigations and research advances help address a fundamental long-term goal: to see how various combinations of large-scale online, mobile-based and social media sensing can be used to (i) understand and predict emerging behaviors of crowds and (ii) detect and explain unusual events, in such public urban spaces. Such insights into the collective behavior of crowds can prove extremely critical for near-time situational awareness in scenarios where military personnel are engaged in short or long-term operations in dense urban areas (e.g., the mega-cities of East and South-East Asia). More specifically, over the project's execution duration, based on interactions and feedback from various AOARD/AFRL/ARL personnel, we have refined our research to specifically address the issue of "anomaly/event detection" in public spaces, based on near-real time analysis of such data streams that capture the online and physical world activities of individuals and urban resources (e.g., taxis and buses).

B. Methodological Details & Results

Our research explored multiple different approaches for fusing online and physical world analytics. From a practical standpoint, the biggest obstacle to conducting research in this area is the ability to obtain a large enough corpus of longitudinal data about the real-world activities of individuals in urban spaces. public spaces. Our research was uniquely placed to address this challenge, as we at SMU have successfully deployed (with support from Singapore's National Research Foundation) a large-scale behavioral observation and experimentation testbed on the SMU campus called LiveLabs [Misra:13][Jayarajah:16a] (www.smu.livelabs.edu.sg). LiveLabs presently involves an opt-in participant pool of close to 3000 students, and uses a combination of infrastructure and mobile-based sensing to collect a variety of different attributes about each participant's activity, include various mobile device usage parameters (e.g., URLs browsed, calendar data, the source and destination IDs of phone calls and SMSes), demographic attributes (e.g., year of study, age, profile of interests) and sensor data (e.g., Wi-Fi scan, accelerometer, barometer and gyroscope traces). Using a fully home-grown and production-quality indoor location system (that has been operational since September 2013), we are also able to collect the indoor location/movement traces of ALL devices on campus that attach to SMU's Wi-Fi network (irrespective of whether the devices belong to LiveLabs participants or not), thereby providing us a corpus of data that has attracted attention from researchers globally.

B.1. Event Detection in Public Urban Spaces

This work focused on the ability to use the location & movement traces of individuals to detect the likely occurrence of unexpected "events" in a variety of urban spaces. The work primarily focused on identifying such events on the SMU campus (one of the sites of the Livelabs testbeds), and also applied the developed algorithmic techniques to the problem of detecting events near MRT (Singapore's extensive network of bus stops and train stations) stations.

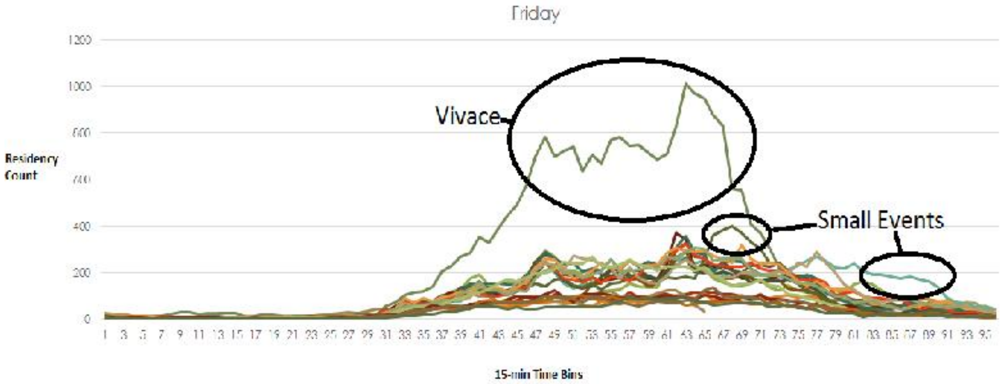

Figure 1: The Occupancy Count of a Recreational Area in the University Campus on Different Fridays of the Academic Term. The x-axis Represents the 96 Fifteen Minute Time Intervals over a Day.

- SMU Campus Event Detection: To tackle this problem, we initially [Nayak:15] developed novel feature extraction techniques on the underlying location and/or group interaction data, and then applied a combination of statistical measures (such as the cosine similarity between different feature vectors) and data clustering techniques (such as K-means or Markov clustering) to identify episodes (and locations) where the collective human behavior is markedly different than those observed under "normal" conditions. Initial analysis in [Nayak:15] showed that features derived from both the absolute value and the trends of "occupancy count" could prove helpful in identify major events on the SMU campus—i.e., events characterized by a large number of participants. While this approach could detect such major events with an accuracy of over 90%, it proved ineffective in identifying smaller events, which typically attracted a smaller set of participants. Figure 1 shows the number of students seen in a specific recreational area on campus where large CCA events typically take place. The large peaks in occupancy correspond to event days.
  To improve the accuracy of such anomaly detection, we subsequently developed [Jayarajah:15b] the notion of using "social ties" among the participants as additional features. In particular, we developed two new families of interaction-based socio-physical properties: (a) group movement and interaction, which provides characterization of the presence of large vs. small groups in the shorter timeframe, and (b) physical interaction-based tie strength, which uses the history of such group interactions to establish social ties among the participants. This was perhaps the first example in the research community on deriving and using social ties, purely from observations on physical world location and movement. These features proved

to be very effective, increasing the overall event detection accuracy from 35% (achieved purely with occupancy-based features) to over 75% (by incorporating such group and tie-strength related features). Figure 2 illustrates the LOF scores observed on different days of the Fall term in 2014 – whilst the occupancy feature detects only one anomaly (LOF score > 1.2), the network features such as the density and mean degree are able to capture more anomalies.

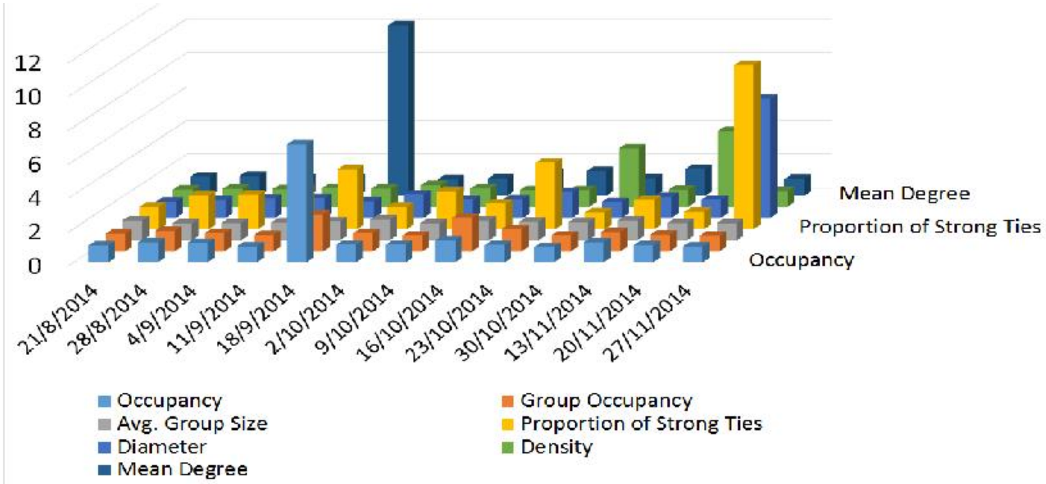

Figure 2: The Local Outlier Factor Scores on Different Days of the Term for Occupancy, Group and Network Features

- City-Scale Anomaly Detection: We showed that the novel technique of socio-physical interaction based features could apply not just to campus environments, but operate at city-scale as well. Using records of MRT transportation data (the entry and egress timestamps and locations of anonymized commuters), we developed a novel form of tie-strength, called frequency factor, to capture the likely coordinated travel by pairs of individuals between common (source, destination) endpoints. Applying known statistical techniques, such as Local Outlier Factor (LOF), enabled us to achieve [Jayarajah:15b] recall value of over 70%, at specific urban venues, simply by using the MRT transportation data.

B.2. Coordinated Urban Mobile Crowdsourcing

We view mobile crowdsourcing as one of the more promising ways of enhanced urban detection. Under this paradigm, residents of the city voluntarily perform a variety of location-specific reporting tasks (such as checking on the cleanliness of restrooms, or the crowdedness of certain urban neighborhoods), often using their mobile devices (e.g., smartphones) to capture and upload such report (e.g., by taking pictures with their smartphones). Such human-generated and human-annotated reports can offer a compelling and low-cost way of corroborating and verifying events and anomalies inferred by our more-automated socio-physical analytical techniques. In this body of work, we have explored and developed novel technologies that increase the participation rate of humans in such large-scale crowdsourcing tasks.

- Coordinated, Push-based Recommendation of Crowdsourcing Tasks: Most existing models of mobile crowdsourcing follow a pull-based paradigm, where individual workers select tasks in a "random" and uncoordinated fashion. Such localized and individualized decision making was known to have several problems, including the phenomenon of super-agents (where a small group of workers monopolize most of the tasks) and the spatial skew of task selection (where only tasks in popularly, highly frequented areas got completed, while tasks in other areas often remained unexecuted). To overcome these limitations, we were the first research group to propose an alternative model of "push-based" crowdsourcing

[Chen:14], where a centralized agent recommended tasks to different workers in a globally coordinated fashion. We developed a novel task recommendation framework, which aimed to maximize the number of tasks allocated cumulatively across all workers, while ensuring that each worker's detour from their normal travel path remained bounded. Using real-world empirical data (of commuter's movement patterns in Singapore), we showed (Figure 3) that this approach resulted in significantly lower detours for workers, promoted greater fairness in task allocation and achieved higher task completion rates. Most notably, we developed a stochastic version of our initial optimization model, which allowed us to achieve these performance gains even when the future paths of individual workers were unknown.

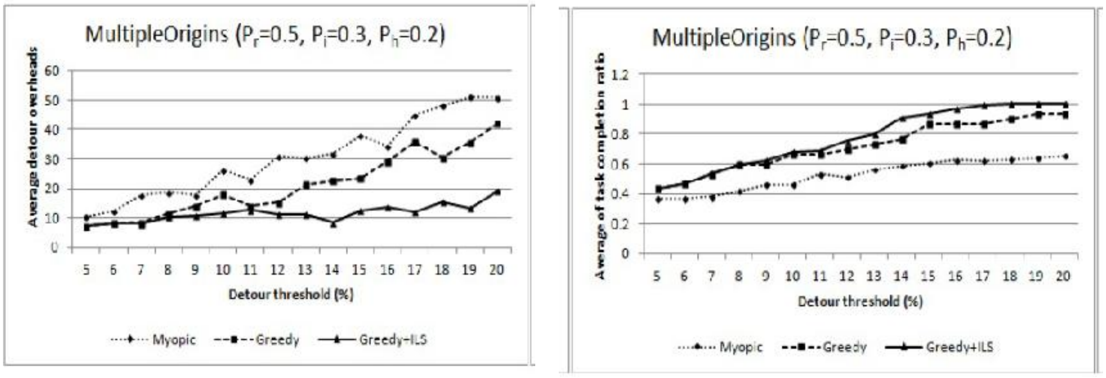

Figure 3: Shows that push-based optimization framework results in (a) lower detour overheads and (b) higher task completion raties in city-scale mobile crowdsourcing.

- Behavioral Incentives and Insights for Improved Mobile Crowdsourcing: Besides theoretically demonstrating the superiority of our push-based coordinated crowdsourcing approach, we additionally focused on empirically determining how other parameters of the crowdsourcing platform can be optimized for enhanced worker participation. To enable such empirical studies, we built and deployed Ta$ker, a campus-based crowdsourcing platform which uses students to perform a variety of location-specific reporting tasks on the SMU campus. Ta$ker itself has been phenomenally successful: it has been used by over 1200 students on a regular basis over the past 2 years, who have performed over 150,000 tasks and helped us realize the vision of a smart campus, augmented by real-time human reporting. In early work, we used limited pilot deployments of Ta$ker [Kandappu:16a] to empirically validate and demonstrate the superiority of the push-based model. Subsequently, we systematically explored various parameters of mobile crowdsourcing and showed [Kandappu:16b] that (i) providing workers a bundle of tasks (as opposed to individual task recommendations) promotes greater productivity, by amortizing the worker's travel overhead, (ii) that the spatial skew in task execution could be satisfactorily tackled via an inverse-occupancy based pricing model (where task rewards were allocated in inverse proportion to the popularity of the corresponding location), and (iii) worker's tendency to generate incorrect reports were not just a function of their intrinsic attributes (their trustworthiness), but also influenced by the sequence in which they performed the tasks in a bundle. Finally, most recently [Kandappu:17], we have shown and explained why task completion rates can be further improved by introducing a dynamic task offloading feature, which allows individual workers to offload a limited number of tasks to their pre-selected buddies.

Overall, this body of work has attracted strong international attraction, and helped establish several principles for large-scale participatory urban mobile crowdsourcing. We continue to conduct research on this topic, including developing mechanisms that can achieve high task completion rates without compromising the location privacy of individual workers.

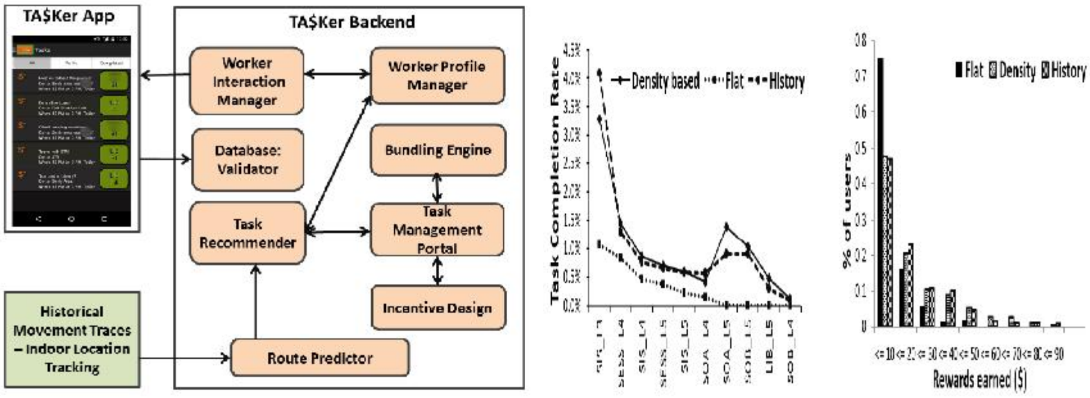

Figure 4: Shows the (a) overall architecture of the Ta$ker application and (b) illustrates how our reverse-occupancy based pricing model helped reduce the skew in task completion rates and rewards earned.

B.3 Multi-modal Social Media Sensing & Urban Profiling

Social media content (e.g., Twitter posts, Instagram media and Foursquare check-ins) contributed by citizens, or social sensors, provide realistic insights into the current trends, sentiments and matters of interest amongst populations. In addition what is expressed online, social sensors also enable capturing of happenings and events in their respective locality. Whilst the captions they author and pictures they upload contain valuable semantic information on the nature of the event, the accompanying metadata such as the timestamp of the post and the geo-coordinates from which it originated aid in localizing the event to a particular region and timeline. In this body of work, we have prescribed the architecture for exploiting such multi-modal, socially sensed data for urban anomaly detection and demonstrated the efficacy of Instagram posts in particular in detecting multiple urban events.

- A Social Sensing Framework for Anomaly Determination: Although the abundance of voluntary, public information enables applications such as detecting anomalies or events, it also presents several key challenges. First, the multimodal nature of information requires exploration of techniques cutting across multiple domains such as computer vision, natural language processing and ontological reasoning to fuse and make sense of the data. Second, unlike the hard sensors discussed in earlier sections of this report (e.g., surveillance camera, accelerometer, etc.), social sensors are influenced by their own views, experiences and association with other individuals, organizations and causes. Hence, it becomes a necessity to investigate the credibility or truthfulness of the posted content. Third, fine-grained localization of detected physical events need to be achieved through incomplete direct (i.e., embedded GPS coordinates) and indirect (e.g., inclusion of street names, landmarks, etc. in the post) mentions of the event venues. We have proposed an architecture for event detection, classification, tracking and anomaly determination using Twitter and Instagram sensor streams, that identifies and addresses the said challenges, and one that is extensible to plug in additional sensor modalities (e.g., video) [Jayarajah:15a].

- Urban Event Detection and Micro-Event Characterization: A key theme we pursue in using social sensing for physical event understanding is in demonstrating the combined utility of content/data and metadata in detecting and characterizing events. We utilized public Instagram posts originating from Singapore during 2016 to quantify the intensity of the haze situation that significantly affected the daily routines of many Singaporeans [Dai:16] where we employed rudimentary image processing techniques on the user-posted images. We extended the study further and validated our hypothesis that the combination of content and metadata can in fact improve our models for estimating the environment haze level from social images [Misra:2016]. We implemented in part the previously proposed architecture and studied transient events such as marathons that evolve in space, time and theme for detecting the large event (e.g., marathon), and in addition, to characterize micro-events (e.g., start and end of the event) that make up the single, large event [Jayarajah:16b]. We extracted Instagram posts related to three international marathon events, filtered out irrelevant using a reverse-image search based approach, employed state-of-the-art image-to-text translation for extracting the semantic labels of images, and show that our techniques are able to achieve a spatial and temporal resolution that is less than 1% and 10%, respectively, of the corresponding ranges for the macro-event in detecting micro-events.

B.4 Socio-Physical Sensing for Urban Events

Figure 5: The Analytics Dashboard Depicting the Next Bus Arrival Times Super-Imposed with the Expected Arrival Times for Bus Service No. 16 at the Bus Stop Opposite of the National Stadium.

- Socio-Physical Analytics using Urban Information Portals: In our previous works, we have considered physical sensors and social sensors as independent modalities for urban analytics and studied them in isolation. Since recently, we are exploring the opportunities and challenges in fusing the two domains. Whilst the physical sensors are well suited for extracting behavior patterns and detecting anomalies, social sensors provide a medium to explain root causes in the event of an anomaly. It is widely accepted that each sensor modality on its own suffers from uncertainty in measurements. Hence, the fusion of the two modalities can result in semantically augmented and more accurate analytics. In realizing this vision, we identified the following key challenges: the individual sensor modalities typically operate at different spatial and temporal resolutions, individual sensors of each modality may not be completely independent (there may be dependencies) and further, there may be dependencies or correlations across the separate modalities. To address these challenges, we propose the depiction of the combined sensor network as a multilayer network with intra-layer and inter-layer links representing the dependencies within and across sensor modalities, respectively. We also propose a fusion operator that derives its meaning from Spatial Pyramid Matching, a popular technique used in computer vision for combining features of multiple spatial granularities in a systematic manner. We have used multiple transport-related sensory data from Singapore including traffic images along major highways, GPS coordinates of available taxis and loading and next bus information of bus services that is available from the public API of the Land Transport Authority of Singapore along with Twitter data from the same period to detect and explain traffic anomalies, which are usually side effects of large and medium scale urban events. Figure 5 is a snapshot of an in-house dashboard that shows the current sensor readings along with the expected normal readings expected for that time. Large deviations are indicative of possible anomalies.

- Improved Group Detection via Multimodal Fusion: Our prior work demonstrated that using group and related interaction features helps improve the accuracy of event detection in urban environments. While our research group had previously developed state-of-the-art WiFi-based group detection algorithms (called GruMon), these algorithms suffered from the limitation that it could only observe individuals carrying WiFi-enabled devices. To further improve the capabilities of event detection, we also initiated work on better group detection technologies that combined WiFi-based movements of individuals with surveillance camera-based monitoring of aggregated movement behavior. In particular, in initial work [Jayarajah:16c], we have demonstrated how the use of video-based sensing of aggregated movement at selected places can complement the pervasive WiFi-based tracking of group interactions. We continue to work on this thread, to ensure that these solutions apply across a network of cameras, distributed across an entire campus.
- On-Demand Mobile Sensing for Urban Event Detection: More recently, in a collaboration with researchers at A*STAR, we have demonstrated how a fusion of participatory mobile sensing and transactional data captured by urban informatics platforms can lead to the detection of unique transportation-related events. The proposed TRAN-SENSE framework [Lu:16] is able to: (1) obtain accurate estimates of wait times at taxi queues by combining large-scale taxi trip data (history of GPS-annotated taxi movement) with individual wait time estimations (based on an application of the QueueVadis [Okoshi:15] system to mobile sensing data); and (2) detect failed boarding attempts on subway trains by combining mobile sensing-based locomotion data with train arrival and departure patterns estimated from RFID-based smartcard transactions at entry and exit turn-stiles. TRANSENSE demonstrates the ability to build a distributed energy-efficient sensing pipeline for large-scale urban event detection, where mobile sensing is instantiated intermittently, only when data from other urban informatics portals indicates a strong likelihood of the individual exhibiting relevant queuing or missed-boarding behavior.

C. Significance and Impact

The research conducted in this project has attracted significant international attention, and resulted in several tangible real-world outcomes. We highlight some of the key initiatives and activities:

- Researcher Exchange and Collaboration with ARL & AFRL: To enhance collaboration between SMU and various DoD agencies, SMU student Ms. Kasthuri Jayarajah spent 3 months in the summer of 2015, visiting the AFRL Discovery Lab at Dayton, OH, where she worked on a multi-agency team (including AFRL and ARL) on "urban situational understanding". Moreover, PI Misra participated in multiple brainstorming meetings at ARL to provide his inputs that helped inform the objectives of the "MINI-DASS" (Mission-Informed Needed Information – Discoverable, Available Sensing Sources (MINI-DASS)) project spearheaded by ARL.

- Large-Scale Crowdsourcing for Participatory Urban Sensing: The investigations into urban mobile crowdsourcing have resulted in the deployment of the Ta$ker mobile crowdsourcing platform n the SMU campus: over the past 2 years, Ta$ker has been used by over 1200 SMU students to perform over 150,000 campus reporting tasks that help inform a "smart campus" portal. Inspired by the success of Ta$ker, Singapore's Ministry of National Development has contracted with SMU researchers, led by PI Misra, to utilize such mobile crowdsourcing techniques as part of their technology-driven approach for city-scale monitoring of municipal resources.
- Establishment of SMU's Center for Applied Smart-Nation Analytics (CASA): Driven in large part by the promise of socio-physical analytics demonstrated by this project, SMU (with PI Misra as the center Director) have been awarded a SGD $3M grant by Singapore's National Research Foundation (NRF) to establish CASA as a new research center focused on urban analytics and applications.
- Invitation as Visiting Researcher to ATI, UK: In recognition of the intellectual novelty and potential impact of the new techniques for urban socio-physical analytics, PI Misra has been appointed as a Visiting Researcher, during April-June 2017, to the Alan Turing Institute (ATI), the UK's national institute for next-generation big data analytics. PI Misra's visit is intended to explore and establish multi-institution Singapore-UK collaboration in the application of such socio-physical analytics technologies for 'Smart City' applications and services.

List of Publications and Significant Collaborations that resulted from your AOARD supported project:

b) Peer-reviewed Conference Proceedings:

[Chen:14] C. Chen, S-F. Cheng, A. Gunawan, A. Misra, K. Dasgupta and D. Chander, TRACCS: Trajectory-Aware Coordinated Urban Crowd-Sourcing, 2nd AAAI Conference on Human Computation and Crowdsourcing (HCOMP), 11/2014.

[Dai:16] B-T. Dai, K. Jayarajah, E-P. Lim, A. Misra and S. Nayak, Study on Singapore Haze, 1st International Workshop on Understanding Situations Through Multimodal Sensing (uSitu'16), 01/2016.

[Jayarajah:14] K. Jayarajah, R. Kauffman and A. Misra, Exploring Variety-Seeking Behavior in Mobile Users, Device Analyzer Workshop (in conjunction with ACM Ubicomp), 09/2014.

[Jayarajah:15a] K. Jayarajah, S. Yao, R. Mutharaju, A. Misra, G. de Mel, J. Skipper, T. Abdelzaher, M. Kolodny, Social Signal Processing for Real-time Situational Understanding: a Vision and Approach, 1st International Workshop on Social Sensing (SocialSens 2015), 10/2015.

[Jayarajah:15b] K. Jayarajah, A. Misra, X. Ruan, E-P. Lim, Event Detection: Exploiting Socio-Physical Interactions in Physical Spaces, IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM), 08/2015.

[Jayarajah:16a] K. Jayarajah, R. Balan, M. Radhakrishnan, A. Misra and Y. Lee, LiveLabs: Enabling In-Situ Behavioural Experiments, 14th International Conference on Mobile Systems, Applications and Services (Mobisys), 06/2016.

[Jayarajah:16b] K. Jayarajah and A. Misra, Can Instagram Posts Help Characterize Urban Micro-Events?, 19th International Conference on Information Fusion (Fusion), 07/2016.

[Jayarajah:16c] K. Jayarajah, Z. Lantra and A. Misra, Fusing WiFi and Video Sensing for Accurate Group Detection in Indoor Spaces, 3rd ACM Workshop on Physical Analytics (WPA'16, in conjunction with ACM Mobisys), 06/2016.

[Kandappu:16a] T. Kandappu, A. Misra, S-F. Cheng, N. Jaiman, C. Chen, H.C. Lau, R. Daratan, D. Chander and K. Dasgupta, Campus-Scale Mobile Crowd-Tasking: Deployment & Behavioral Insights, ACM Conference on Computer Supported Collaborative Work and Social Computing (CSCW), 02/2016. (Honorable Mention—top 5% of papers)

[Kandappu:17] T. Kandappu, A. Misra, R. Daratan, Collaboration Trumps Homophily in Urban Mobile Crowdsourcing, ACM Conference on Computer Supported Collaborative Work and Social Computing (CSCW), 02/2017.

[Lu:16] Y. Lu, A. Misra, W. Su and H. Wu, Smartphone Sensing Meets Transport Data: A Collaborative Framework for Transportation Service Analytics, under submission, IEEE Transactions on Mobile Computing (TMC).

[Misra:13] A. Misra and R. Balan, LiveLabs: Initial Reflections on Building a Large-scale Mobile Behavioral Experimentation Testbed, ACM Mobile Computing and Communications Review (MC2R), 10/2013.

[Misra:14] A. Misra, K. Jayarajah, S. Nayak, P. Prasetyo and E-P. Lim, Socio-Physical Analytics: Challenges & Opportunities for Fusing Mobile and Online Sensing, 1st ACM Workshop on Physical Analytics (in conjunction with ACM Mobisys), 06/2014.

[Misra:16] A. Misra, Z. Lantra and K. Jayarajah, Ontology-aided Feature Correlation for Multi-Modal Urban Sensing, SPIE DSS conference, 04/2016.

[Nayak:15] S. Nayak, A. Misra, E-P. Lim and P. Prasetyo, Exploring discriminative features for anomaly detection in public spaces, SPIE DSS Symposium, 04/2015.

[Okoshi:15] T. Okoshi, L. Yu, C. Vig, Y. Lee, R. Balan and A. Misra, QueueVadis : Queuing Analytics Using Smartphones, IEEE/ACM IPSN, April 2015.

d) Conference Presentations/Keynote/Invited Talks (without papers):

- A. Misra, Mobile/Wearable & Urban Sensing and Analytics, International Conference on Networking, Systems and Security (NSysS), 01/2017.
- A. Misra, Mobile Crowdsourcing: An Enabler of Smart Nation Services, International Conference on Collective Human Intelligence and Crowdsourcing Applications (IHCICA), 10/2016.
- A. Misra, Crowdsourcing: A Building Block for Smart Cities, 1st International Workshop on Context-Aware Smart Cities and Intelligent Transport System (AwareCities), 03/2016.
- A. Misra, Mobile Analytics@LiveLabs: Capturing Human Behavior in Urban Public Spaces, 2nd International Conference on Applications and Innovations in Mobile Computing (AIMOC), 02/2015.
- E-P. Lim, From Big Data to Smart Nation: The Social Media Mining Perspective, Workshop on Sentiment Elicitation from Natural Text for Information Retrieval and Extraction (SENTIRE), in conjunction with IEEE International Conference on Data Mining (ICDM), 12/2014.
- A. Misra, Lessons Learnt@LiveLabs: Opportunities and Challenges in Practical Socio-Physical Sensing, 3rd ACM Workshop on Mobile Systems for Computational Social Science (MCSS), 09/2014.
- A. Misra, Group Analytics: Understanding and Predicting Human Behavior in Urban Public

Spaces, 7th International Conference on COMmunication Systems & NETworkS (COMSNETS), 01/2015.

- A. Misra, Participatory Sensing in Action for Urban Lifestyle Applications, IEEE 9th International Symposium on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), 04/2014.
- E-P. Lim, Social Media Analytics for Better Urban Living, The Third Cities Roundtable Workshop, hosted by Singapore's Ministry of National Development, 11/2014

f) Significant interactions with AFRL, ARL, Industry etc.

- Collaboration with Dr. Rob Williams and Dr. Julie Skipper, AFRL Discovery Lab, resulting in summer research visit in 2015 by Ms. Kasthuri Jayarajah and joint work under the auspices of the Situational Understanding Research Institute
- Collaboration with Mr. Mike Kolodny and Dr. Tien Pham, Army Research Lab, Adelphi, MD, resulting in participation and joint work for the MINI-DASS project, with special focus on social media sensing

Attachments: Publications b) listed above. Note that the attachments include both papers that were directly funded by AOARD funds and other papers that are related to, and augment the, AOARD research topics, but that were performed using funding from other ongoing funded projects.

DD882: As a separate document, please complete and sign the inventions disclosure form.