Mobile Sensor Analytics Research: The Michigan Advantage

Mobile sensor research: its potential and data science challenges

Mobile sensing devices are taking on an increasing presence in our lives, connecting individuals with their environments, and connecting the present of an individual with his past and future. People wear wristbands, rings and helmets, and use smartphones and similar devices to record physiological, cognitive and behavioral measures. Such data can inform healthcare providers and patients to improve health maintenance, and can improve exercise efficiency, sports performance, and entertainment experience. Mobile sensors are being deployed in vehicles to measure vehicle kinematics, record driver behavior, and increase perimeter awareness. New generations of multi-function mobile sensors are also being deployed in scientific research such as social behavior modeling, environmental monitoring, and epidemiological tracking. Mobile sensing devices are also critical in order for smart grids and smart cities to operate. In short, in future society where everything and everyone is connected, almost all aspects of life will involve sensing, especially mobile sensing.

The vast scope and profound depth of research at the University of Michigan (U-M) guarantee that mobile sensing is a recurring theme in research across many of U-M's colleges and schools, and is an integral part in U-M clinical and health research, transportation research, exercise science, natural resources and environmental research, civil engineering, behavioral science, human development, and many other research areas. The Michigan Institute for Data Science (MIDAS) recently organized a Mobile Sensor Analytics research working group, with the goal of advancing innovation, multi-disciplinary collaboration and methodology in mobile sensor research.

MIDAS' interest in mobile sensor analytics also lies in the fact that there are significant data science opportunities for theory and application in mobile sensor analytics. Mobile sensing devices produce reams of data; and the data collection, processing and interpretation touch upon many key issues in data science methodology that have impact far beyond mobile sensing. These methodological issues include, but are not limited to:

- real-time data streaming and analysis
- active on-line learning
- integration of data in various forms, spatiotemporal scales, granularity and quality.
- mobile sensor networks analysis
- energy-efficient mobile computing
- high-dimensional data reduction
- sensor data privacy and ownership

Given the impact on data science methodology and the broad applications of mobile sensor analytics, it is no surprise that our working group has attracted wide interest from researchers in many U-M schools and colleges.

Harnessing U-M research strength, the collaborative culture, and the institutional commitment to data science

The MIDAS Mobile Sensor Analytics working group meets monthly to discuss research ideas, potential funding opportunities and collaboration. Currently, our group has more than 60 researchers from all three U-M campuses (Ann Arbor, Dearborn and Flint), seven U-M (Ann Arbor campus) schools, colleges and research institutes, as well as companies in the area. The Ann Arbor campus schools and colleges represented in our group include the College of

Engineering, the Medical School, the College of Literature, Science and the Arts, the School of Public Health, the School of Kinesiology, the Institute for Social Research and the U-M Transportation Research Institute.

With such diverse membership, our working group is harnessing the breadth and depth of U-M research and its collaborative culture, which has the following key strength:

- U-M possesses deep and broad expertise in the theory and methodology of data science, including math, statistics and computer science;
- As one of the largest and best research universities in the world, our research strength spans many fields, thus creating a huge playground for researchers to apply mobile sensing technology and analysis to many research fields. Many researchers in the world-class Medical School, College of Engineering, Institute for Social Research, School of Public Health, Ross School of Business and other research units are leaders in their research domains.
- U-M has been regarded as one of the most collegial universities in the US, and the collaborative culture is ideal for mobile sensing research, which thrives from both cutting-edge data science methodology and real-world challenges;
- Our extensive alliance with industry and the government has already made UM one of the most influential universities in the Midwest and in the nation.

Mobile sensing research will also be bolstered by the institutional commitment to data science. U-M has already started a number of multidisciplinary programs, such as the Data Science Initiative, the Personalized Health Initiative, the Michigan Center for Integrative Research in Critical Care and the Exercise and Sport Science Initiative. All of these initiatives touch upon mobile sensing research, and provide synergy to U-M researchers.

MIDAS, the host of the Mobile Sensor Analytics working group, was created through the Data Science Initiative, which was launched in 2015 with a committed investment of $100 million over five years. This visionary Initiative brought together existing data science consultation and computing resources to form a comprehensive home for data science research and education and aims to capture the momentum and vast talent at U-M to propel us to the forefront of data science nationally and internationally. MIDAS is the major player in the Data Science Initiative, and its roles include:

Research infrastructure	Help U-M researchers access key datasets locally, nationally, and internationally; contribute conceptually as UM creates centralized computing infrastructure for data management, storage, analytics, and training
Data Science research	Help domain scientists and data science methodology experts coalesce toward an intellectual core that transcends domains; foster new methodological approaches to big data through interdisciplinary research initiatives
Multi-investigator, multi-disciplinary, multi-institutional collaboration	Build partnership with academic institutions, businesses and governments for national and international collaboration
Education	Transform data science education to a multi-disciplinary curriculum so that students are firmly grounded in theory, methodology and their applications

Mobile sensor analytics is a perfect example of how MIDAS can impact research by bringing together research strength from across U-M campuses and developing UM expertise in handling crosscutting challenges in data science with impact on all research domains. The data science methodology and best practices developed in mobile sensor analytics will also “trickle down” to other research areas as well.

Partnering with industry

Mobile sensor research is receiving increasingly more attention from researchers and stakeholders, and is supported by federal agencies such as the National Science Foundation, the National Institute of Health, and the Department of Defense. However, for mobile sensor research to positively impact the society, the collaboration of academia and industry is indispensable. The industry is our partners in research, employers for our students, vendors for our infrastructure, and an invaluable source of real-world problems to ground our research and education. MIDAS is working closely with U-M Business Engagement Center to forge industry partnerships. Many members of our Mobile Sensor Analytics group have also expressed strong interest in working with industry; some already have a long history working with industry. We welcome collaborations based on individual research projects that are jointly selected by the companies and U-M researchers. The companies can also identify and support a number of research projects with the same theme or addressing the same real-world problem from multiple perspectives. Each company’s relationship with MIDAS will be determined on a case-by-case basis through extensive discussion.

Working with U-M researchers, industry partners will be able to tap into the research talent at U-M, access the newest methodology and discoveries in data science and mobile sensor research, attract data science students for internship and employment, and influence mobile sensor research at U-M through their insight in the real-world data science challenges.

Select projects of mobile sensor analytics research at U-M

Below, we highlight some of the ongoing or planned mobile sensor analytics research at U-M, and some prominent researchers. We categorize the research into: 1) Mobile sensors for health sciences; 2) Mobile sensors for exercise; 3) Mobile sensors for transportation research; 4) Mobile sensor hardware development; 5) Mobile sensor research infrastructure; and 6) Mobile sensor analytics methodology. Note that these are a small sample of U-M research in these areas, and both the number of researchers and the scope of research are much larger than what these snapshots demonstrate.

Mobile Sensors for Health Sciences

Wearable data collection for the study of the exposome. Dr. Alfred Hero (Professor, Electrical Engineering and Computer Science, Biomedical Engineering, and Statistics) develops methodology for extracting information from wearable physiological sensors to establish a personalized baseline of health. The human host is exposed to many perturbations over a lifetime yet remains healthy most of the time. These exposures can be in the forms of stressors, infection, exercise, sleep disruption, drug use, etc, and the aggregate response of the human host to these exposures is called the exposome. The exposome can be studied over time over a population by running experiments that collect data from wearable devices while the subjects in the experiments undergo controlled and uncontrolled perturbations. With his collaborators at U-M, Duke University, University of Virginia, and University of London, Dr. Hero is developing a database from experiments and challenge studies involving hundreds of human subjects exposed to various respiratory viruses for which the reaction of their exposome is observed over long time periods. The data that comes from wearable devices for this study include blood volume pulse, heart rate, electrodermal activity, skin temperature, and actigrams representing physical movement. From this database, Dr. Hero combines methods of statistical signal processing, machine learning, and data fusion to develop mathematical models for exposome dynamics, i.e. healthy and unhealthy deviations from a person's baseline. An example of healthy deviation is the natural cycling of physio-molecular biomarkers that follows fluctuations in the circadian rhythm. An example of unhealthy deviation is the onset of infection and viral shedding following the exposure to a virus. Dr. Hero's model can detect molecular and physiological signatures that can predict unhealthy deviations from baseline due to exposure to pathogens, and classify a person's susceptibility to illness or other perturbation. Dr. Hero is interested in collaborating with others to collect wearable data on large cohorts for studying human behaviors, diseases, and reactions to general exposures.

Wearable Physiological/Behavioral Health Monitoring. Wearable health technology is drawing significant attention for good reasons. The information extracted from these systems will enable emerging applications in healthcare, wellness, emergency response, fitness monitoring, elderly care support, long-term preventive chronic care, assistive care, smart environments, sports, gaming, and entertainment. Despite the ground-breaking potentials, there are a number of challenges in the design and development of wearable medical embedded systems. Due to limited resources in wearable processing architecture, power efficiency is essential to allow unobtrusive and long-term operation of the hardware. Also, the data-intensive nature of continuous health monitoring requires efficient signal processing and data analytics algorithms for real-time, scalable, reliable, accurate, and secure extraction of relevant information from an overwhelming amount of data. Dr. Omid Dehzangi (Assistant Professor, Computer and Information Science, UM-Dearborn) designs and develops seamless and ubiquitous monitoring of different modalities of physiological (e.g. EEG, ECG, GSR, EMG, body temperature) and behavioral (motion, activities, habits) recordings via wearables for human state identification and point-of-care intervention. The goal of his research is to incorporate multi-modal continuous data to discover the objective relationship between human physiological and behavioral states using signal processing and artificial intelligence algorithms.

Using cell phone speech data to predict the onset of Bipolar mood states. It has been long recognized that speech patterns, such as the tone, the speed, and the rhythm, are modulated by the emotional and neuropsychological states of the speaker. There is widespread interest in using speech data as the proxy for mental health states for patients with Depression, Bipolar Disorder, Autism and Post-Traumatic Stress Disorder. Dr. Melvin McInnis (Thomas B. and Nancy Upjohn Woodworth Professor, Psychiatry, Medical School) and his team have developed a program, PRIORI (Predicting Individual Outcomes for Rapid Intervention), that analyzes acoustics of speech as predictors of mood states from mobile smartphone data. A major advantage of this approach is that the data comes from ecologically valid sources (phone calls) instead of controlled laboratory or clinical settings, and scaling up the data collection is inexpensive and can be done remotely. Using state-of-the-art acoustic signal processing, feature extraction, data modeling and machine learning methods, the team is able to achieve high performance in mood identification with recordings from different phones with variability in clipping, loudness and noise. In particular, the team has shown that this program is effective in distinguishing the manic and depressive states of patients with Bipolar Disorder and in predicting impending mood states.

The lead data science methodologist and speech analysis specialist on the team is Dr. Emily Mower Provost (Assistant Professor, Electrical Engineering and Computer Science, College of Engineering). Her research interests are in behavior recognition from audio-visual signals, focusing on affective computing and assistive technology. Her research in affective computing seeks to design new emotion classification systems that are robust and accurate while providing insight into the temporal properties that underlie emotional communication. She also seeks to create new speech processing tools that enable real-time mental health monitoring and promote individualized recovery. She received the Oscar Stern Award for Depression Research (2015) and a National Science Foundation CAREER award (2017).

Data science in clinical decision making. Dr. Kayvan Najarian (Associate Professor, Computational Medicine and Bioinformatics) focuses on the design of signal/image processing and machine learning methods to create computer-assisted clinical decision support systems that improve patient care and reduce the cost of healthcare. His team also designs wearable and other mobile sensors to collect and analyze physiological signals and images for clinical decisions and for home monitoring. Dr. Najarian collaborates extensively with clinical researchers to apply his expertise in data science methodology to healthcare research. Specific areas of application include decision support systems in the management of traumatic brain injuries, spinal cord injury, traumatic pelvic/abdominal injuries and hemorrhagic shock, cardiac arrest, postoperative care and other critical care states. One of his most recent projects, in collaboration with Dr. Kevin Ward and MCIRCC, aims to develop large-scale analytic tools for the high-volume and high-velocity data that are generated by a large variety of sensors and monitors in the ICU.

A wearable device for individualized physical rehabilitation. Dr. Samir Rawashdeh (Assistant Professor, Electrical and Computer Engineering, U-M, Dearborn) is developing a Rehab Buddy device, a rehabilitation assistance system that extends the reach of a physical rehabilitation specialist beyond the clinic. This device could address two frequent issues in unsupervised musculoskeletal rehabilitation: poor intervention adherence and the lack of objective tracking. The device uses body-worn inertial measurement units and a mobile application that provides feedback to the patient to ensure that home exercises are performed with the same precision as under clinical supervision. Initially, the individualized parameters of the exercise will be determined and captured by the sensors and the user interface with the supervision of a specialist in the clinic; the system will then provide the patient with real-time corrective feedback. The development will include the sensing system, its associated kinematic processing algorithms, and several forms of real-time corrective feedback approaches.

During the development of a general framework for this device, methods will be developed for inertial measurement unit signal processing, identifying parameters that define custom exercises, and providing precise feedback. Since such methods are lacking, this line of research will have broader methodological impact in addition to potentially improve the effectiveness and motivation of the patients to manage their injury through exercise.

Automatic and continuous optimization of assistive robotic devices: The usefulness of assistive robotic devices, such as active prostheses and robotic exoskeletons, is often assessed by how well the device can achieve a physiological objective. The objective could be a reduction in the user's pain or the energy cost of the device, or an improvement in gait symmetry, or an increase in walking and running speed or endurance. In order to yield optimal performance, the controllers embedded in the software of the robotic devices need to be adapted and tuned on a subject-specific basis. Dr. C. David Remy (Assistant Professor, Mechanical Engineering, College of Engineering) and his team are the first to demonstrate that the tuning process can be automated. They use real-time physiological measurements while the user is wearing and using the device. The measurements are sent to a computerized optimization algorithm that automatically changes the parameter settings of the controller until optimal values are found for the specific user. The team first applied this ‘body-in-the-loop' optimization approach to tune a bilateral ankle exoskeleton as the assistive device, with the reduction in energy cost as the objective.

This approach has the potential to greatly improve the design, control, and evaluation of assistive robotic devices and other systems that interact closely with human users, such as sports equipment, exercise machines, and automated training systems. The optimization can happen when the device is designed, every time it is fitted to a new user, and on a continuous basis in order to adapt to a changing environment or when the user's physiological condition changes. The team's research on the methodology and algorithms for data collection, processing, optimization, and the design and control of robotic devices will also have broader impact on the optimization of other mobile devices.

Identifying real-time data predictors of stress and depression using mobile technology: One robust finding in depression research is that life stress is the single most important trigger of depressive episodes. Understanding how life stress leads to depression has the potential to transform our ability to prevent and treat depression. Dr. Srijan Sen (Professor, Psychiatry, Medical School) and his team have demonstrated that the onset of stress and depression can be predicted in a specific group of individuals: medical interns. Medical internship, the first year of professional medical training, is characterized by long work hours, emotionally difficult situations and inconsistent and insufficient sleep. Internship is a rare situation whereby the onset of a major, uniform stressor and a dramatic increase in depressive symptoms can be accurately predicted.

Dr. Sen's team is now developing an app platform that integrates mobile phone signals and wearable data, to determine the dynamic relationships between mood, sleep, and circadian rhythms, and micro-randomized intervention for depression under stress. The team will build personalized models of sleep, circadian rhythms, physical activity, and mood, and optimize the efficacy of mobile sensor to detect depression onset. The researchers hope that, when real-time data on an individual is fit to the right mathematical model, individuals at risk can be identified early and provided the right treatment at the right time. The impact of this project goes beyond depression. Advanced tools and models with large-scale computing power and data integration capacity are critical in studying the interaction of physiology, psychosocial behavior and environment in real-time, and their contribution to mental illness risks. Dr. Sen's team's multi-disciplinary approach in analyzing real-time, multi-modal mobile data can therefore be generalized to the prediction of onset and preventive treatment of many other diseases.

Optimizing sleep timing and duration with smartphone app: Light is a key element that keeps one's circadian rhythm (therefore sleep timing and duration) in sync with the environment, and one can shift his/her circadian clock to a new pattern by controlling the light in the surroundings. People who need to adjust their sleep patterns include travelers, workers of evening shifts, patients with sleep disorders and athletes who need to align their circadian clocks with teammates and the timing of the competitions. Drs. Olivia Walch (Postdoctoral Fellow, Neurology, Medical School), Cathy Goldstein (Assistant Professor, Neurology, Medical School) and Danny Forger (Professor, Mathematics, College of Literature, Science and the Arts) are developing software and apps which allow users to track their sleep duration and timing. They incorporate activity tracking and use well-established sleep and circadian science, as well as validated mathematical algorithms, to estimate both circadian state and sleep. Users are provided with lighting and lifestyle recommendations (such as when to seek or avoid light) to optimally shift circadian phase and improve sleep duration and quality.

This research has already been implemented in one mobile app for travelers, Entrain, which provides lighting instructions to help travelers adjust to a new time zone as quickly as possible. Since its release in 2014, Entrain has been downloaded over 200,000 times. Currently, the work is being extended into applications for shift workers, athletes, and as a general circadian wellness tool.

Wearable sensing: from the ICU to the home. Dr. Kevin Ward (Professor, Emergency Medicine, Medical School) and the Michigan Center for Integrative Research in Critical Care (MCIRCC) that he directs are national leaders in critical care research. The research at MCIRCC encompasses understanding and developing diagnostics, monitors and therapeutics for sepsis, cardiac arrest and cardiogenic shock, acute neurologic catastrophes such as traumatic brain injury, hemorrhagic stroke, and acute spinal cord injury. MCIRCC's innovation has broad impact on critical care for a wide range of medical conditions and for trauma and combat casualty care.

One of the research areas that MCIRCC excels at is using data science to develop wearable sensors that will greatly impact the monitoring, diagnosis and treatment of critically ill and injured patients. They are developing a growing number of products in this area. The following are a few examples. 1) The Piezo Ring. This is a sensor worn on the finger that continually measures a new physiological signal–the vascular tone and reactivity of small blood vessels in the finger. It detects potential cardiovascular events and hypotension much earlier than the traditional cuff system – it can predict hypotension more than an hour in advance. It connects to any portable device or monitor and has practical applications in dialysis centers, combat situations, emergency rooms, ICUs, ambulances, and eventually in a patient's home. 2) Dynamic Respiratory Impedance Volume Evaluation (DRIVE). DRIVE monitors a patient's circulating blood volume non-invasively, as well as respiratory rate and quality. It is supported by a small wearable, wireless device that provides personalized, continuous, and easily interpreted diagnostic data. It assesses functional volume by utilizing changes in limb blood volume produced by breathing as measured by changes in impedance of the limb. This non-invasive method rids the risks of a more invasive treatment and can be applied to a variety of managed-care environments, from emergency room to clinics to the patient's home. 3) A novel analytic tool based on machine learning that can be incorporated into any wearable ECG patch or monitor for monitoring hemodynamic instability. This system continuously monitors and assesses hemodynamic conditions for the early prediction of deleterious hemodynamic events. 4) A goggle/headband that combines piezoelectric and impedance technology to provides cerebral blood volume and autoregulation as well as respiratory rate and quality monitoring, for precise therapy for traumatic brain injury, stroke,brain tumors and sleep. MCIRCC has also developed novel signal and signal quality processing as well as advanced machine learning approaches that incorporate high velocity and heterogenous structured and unstructured data from critical care monitors and the electronic medical record that are being used to inform the design and implementation of its wearable sensors.

Mobile Sensors for Exercise

Monitoring exercise performance in diseased populations: Monitoring the number of daily "steps" using mobile devices has become a common practice. However, this crude measure of physical activity has great room for improvement because the mere number of steps alone does not provide enough information in order to optimize the physical activities to reap health-related benefits and improve sports performance. Dr. Peter Bodary (Clinical Assistant Professor, School of Kinesiology) has expertise in exercise and cardiovascular physiology and wearable technology for physical activity, health and sport performance. He uses commercially available "muscle oxygen monitors" (Near-infrared spectroscopy; Moxy Sensor) to measure changes in muscle tissue oxygenation, and aims to incorporate more measures to optimize exercise effectiveness for patients. Seeking more sensitive mobile sensors, new algorithms for heart rate variability, blood pressure alterations and other measures, he is collaborating with the Michigan Center for Integrative Research in Critical Care (M-CIRCC, led by Dr. Kevin Ward, see the Health Science section above). He teaches a course using "wearable technology" where the senior- and graduate-level students design experiments using recent technology and interact with companies from the wearable technology sector.

Mobile Sensors for Transportation Research

Predicting travel route choices based on mobile sensor data: In an era of automated and connected transportation, it is essential to integrate bicyclists and pedestrians into a smart infrastructure to facilitate mixed mode travel. A research team at the U-M Transportation Research Institute (UMTRI) is working to use sensor data to understand route choices and other travel behavior of pedestrians and cyclists. The team has expertise in three disciplines. Dr. Carol Flannagan (Research Associate Professor, UMTRI) is an experimental psychologist and is widely recognized for her expertise in transportation data management, safety data analysis and statistics. Dr. H.V. Jagadish (Bernard A Galler Collegiate Professor of Electrical Engineering and Computer Science, College of Engineering, also see the Methodology section below) is an expert in database management and database design. Dr. Aditi Misra (Assistant Research Scientist, UMTRI) has expertise in participatory planning, GPS data handling and curating and route choice modelling of vulnerable road users. Dr. Robert Hampshire (Research Assistant Professor, UMTRI) is an expert in bike-sharing, bike-share rebalancing and network optimization.

The team currently uses cell phone data to identify and predict route choices made by people from different backgrounds and with different preferences. However, a number of problems need to be solved in order for cell phone data to be used reliably. For example, cell phone based GPS data must be processed so that a trip follows the existing roads. GPS based location data also suffer from multiple sources of error including inaccuracies in location tracking. In addition, cell phone signal loss leads to missing data, discontinuous trip segments and ambiguities at intersections. These issues become more complicated for large networks and in real-time analysis. While working on trip pattern identification and prediction with cell phone data, this research team is also developing efficient map matching and route prediction algorithms from sparse data. The methodology thus developed will have much broader applications for other types of research that involve real-time, sparse and network data.

Mobile Sensor Hardware Development

Arborsense – developing wearable biochemical sensors: Drs. Girish Kulkami (Postdoctoral Fellow), Xudong Fan (Professor, Biomedical Engineering, College of Engineering) and Zhaohui Zhong (Associate Professor, Electrical Engineering and Computer Science, College of Engineering) founded Arborsense, a company that develops wearable biochemical sensors. The goal of Arborsense is to become a dominant player in wearable healthcare device market by filling the niche of wearable biochemical sensor, and providing a personal health companion to enable accurate decision-making in healthcare, fitness and sports. The majority of Arborsense's funding comes from the National Science Foundation's SBIR grant. Their sensors utilize a new graphene-based nanoelectronics vapor sensing technology (developed and patented at U-M). These sensors accurately and quickly measure chemicals in the sweat that are indicators of dehydration, muscle fatigue, stress, sugar level, diabetes, alcohol consumption, and drug use. The sensors will have wide applications in healthcare, personal care, fitness, sports, and law enforcement. Currently, the team is focusing on an alcohol sensor, which could fulfill the unmet need for an accurate, light, non-invasive and discreet device for the continuous monitoring of alcohol consumption.

The founders of Arborsense complement each other with strong research and development expertise in a few areas. Dr. Kulkami is experienced in nanoelectronic biochemical sensor development and has expertise in carbon-based materials for gas sensing. Dr. Fan has had many years' experience in gas/liquid sensor platform development, and has worked with the National Institute of Health and the Environmental Protection Agency for healthcare and environmental monitoring applications. Dr. Zhong is an expert in nanomaterial physics and applications and carbon-based nano-electronics.

Mobile sensor for high-precision, high-accuracy localization: Dr. Mark Moldwin (Arthur F. Thurnau Professor, Climate and Space Sciences and Engineering, College of Engineering) and his team are developing wireless devices that enable high-precision, high-accuracy personal indoor localization. The technology uses a fusion of magnetic or ultra-wide band beacons in combination of inertial measurement units. His team includes Dr. Lauro Ojeda (Assistant Research Scientist, Mechanical Engineering), Dr. Perry Samson (Arthur F. Thurnau Professor, Climate and Space Sciences and Engineering, College of Engineering) and Dr. Judy Yu (Engineer, College of Engineering). They also work with U-M's Digital Innovation Greenhouse with support from UM Academic Innovations to build the back-end software.

The team is currently testing these sensors in the classroom to enable students to be immersed in simulations in which their location can sample or influence the virtual environment. For example, in an interactive session about atmospheric pressure, each student can be assigned an atmospheric pressure level and then all students are asked to create a hurricane. Their positions in the room, accurately determined by the new sensors, are projected onto a map and wind speed is determined by the gradients of pressure between the students. The students will need to communicate with each other and reposition themselves physically to produce a specified pressure configuration. In a public health classroom, each student can be randomly assigned to be a disease vector and to be either immunized or not. Students then network through the classroom meeting other students. They can then play back their path through the classroom to understand the disease spread and the effect of vaccination. The high-precision, high-accuracy localization sensors, however, have much broader impact for all research areas where precise and accurate localization is needed.

Mobile Sensor Research Infrastructure

U-M HomeLab research facility: The U-M HomeLab is operated by the BioSocial Methods Collaborative, a methods hub at the U-M Institute for Social Research (ISR). The U-M HomeLab is a state-of-the-art apartment for multi-modal biosocial research with the capability of accommodating individuals with disabilities. The 985 sq. ft. apartment provides a realistic homelike environment and is equipped with fully functioning kitchen, bath and laundry. The flexible bedroom space can be turned into a small store, dorm room, office, waiting room, etc.

depending on the need of each research project. In addition, there are stairs, hallways and loft space. This research facility has a fully integrated AV camera, speaker and microphone system, as well as a customizable lighting system that can be programed to mimic different times of the day. It is also equipped with signal technology (cable, wired/wireless internet and cell phone), terabytes of short-term data storage, an HVAC system to control humidity and an integrated suite of on-the-body physiology sensors as well as environmental sensors such as the Microsoft Kinect. The researchers in the control room can view (through one-way windows), control and communicate with the research participants and sensors. The BioSocial Methods Collaborative is actively engaged in collaborative research with industry partners.

Mobile Sensor Analytics Methodology

Database management: One of the national leaders in information management research is Dr. H. V. Jagadish (Bernard A Galler Collegiate Professor, Electrical Engineering and Computer Science, College of Engineering). A central theme of Dr. Jagadish's research is how to build database systems and query models so that they are truly usable, and how to design analytics processes so that they can deliver real insight to non-technical decision-makers. Usability is not just a question of having a well-designed user interface; it has to enable users to ask precise questions through an understanding of the database structure and organization. The issue of usability is relevant to many aspects of mobile sensor analytics, such as data modeling, schema (database organization and structure) design, schema summarization, natural language querying, and analytics with missing data and imprecise queries. One usability issue that is particularly relevant to mobile sensor data is the integration of data from multiple, heterogeneous sources, and has undergone many manipulations. A related question is how to design effective, usable database systems such as those using visual analytics so as to help users find visually recognizable patterns in large complex data sets rather than just using a data mining algorithm. All these fundamental issues of database management could have significant impact on how we process and use mobile sensor data.

Dr. Jagadish's work is supported by the National Science Foundation through multiple grants. He has also worked with multiple industry partners.

The integration and analysis of high dimensional and heterogeneous data: Heterogeneous data integration and high dimensional data are challenges for almost all Big Data research, and highlighted by mobile sensor research. One of the research focus areas of Dr. Judy Jin (Professor, Industrial and Operations Engineering, College of Engineering) is on developing data integration and analysis methodologies that will have broad impact in mobile sensor research. Specifically, 1) Her research uses multiple statistical models (the causal probability network model, statistical change point detection, set-covering optimization, and hierarchical lasso regression methods) to improve sensor selection, placement, and signal feature extraction so that it is easier to detect system anomaly and predict performance. 2) She uses nonparametric modeling (e.g. wavelets, spline, PCA, SVD, ICA, SCA) and multi-way tensor data analysis for the analysis of patterns in multiple sensor signals, such as multi-stream waveform signals, image and video data. 3) She also develops spatiotemporal modeling and advanced machine learning methods for the adaptive sampling and analysis of products shape variations.

The methodologies that she develops are currently used in several application areas involving mobile sensors, including: 1) Integrating sensor data for quality control of the manufacturing process and making machine maintenance decisions in metalwork; 2) modeling and analysis of human body movement data while they drive to improve vehicle design and detect distracted driving behavior; 3) analysis of vehicle crash test data to improve vehicle design and driving safety; 4) analysis of patient gait data to improve clinic decision; 5) using machine learning for variable selection and classification in the analysis of mixed types of electronic health record data for clinic decision-making.

Dynamic networks: Using data-driven and dynamics-based methods, Dr. Necmiye Ozay (Assistant Professor, Electrical Engineering and Computer Science, College of Engineering) develops theory and algorithmic tools for compactly representing and analyzing heterogeneous data from sensors and other information-rich networked dynamical systems. Her group also studies structural properties of networks and dynamical systems to understand fundamental limitations of anomaly detection in the data from these systems, and designs passive and active monitors to detect anomaly. Dynamical models naturally capture temporal relations within data streams, and sometimes uncover causal relations. Moreover, one can use hybrid and networked dynamical models to capture logical relations and interactions between different data sources. By recasting information extraction problem as a networked hybrid system identification problem, they can use tools from computer science, system and control theory and convex optimization to efficiently and rigorously analyze and organize information. Dr. Ozay's team would like to collaborate with domain scientists to apply the developed methodologies in the context of change and anomaly detection in mobile sensor data analytics.

Machine learning in health research: Dr. Ambuj Tewari (Assistant Professor, Statistics, College of Literature, Science and the Arts) is a machine learning expert. His research includes working on the mathematical foundations of machine learning algorithms as well as finding new application areas for machine learning. Methodological topics that he has recently worked on include statistical learning theory, online learning, bandit problems, reinforcement learning, high-dimensional statistics, and optimization for large-scale learning. Collaborating with U-M researchers, Dr. Tewari is also applying machine learning to research problems in behavioral sciences, computational chemistry, computational biology, learning sciences, complex networks, and personalized, real-time, mobile health interventions.

Mobile sensor research in health sciences comes with challenges that motivate the development of new methodologies that could have much broader impact. Dr. Tewari is interested in applying her expertise to some of these challenges such as data imputation; data privacy and security; respecting constraints in computation, battery or communication; heterogeneity in human behavior; building computational models of human behavior; dealing with multiple scales in data; and enabling reproducibility of mobile health studies. He is especially interested in partnering with industry to run large-scale studies on multiple health behaviors (physical activity/nutrition/sleep/stress), and mental disorders, especially depression.