Research Statement

"Toward Transformative Digital Health"

Camellia Zakaria (Ph.D.)
University of Massachusetts Amherst
nurcamellia@umass.edu

In the last decade, we witnessed progressive expansion in digital health technologies, redefining what counts as 'health.' *Am I experiencing an irregular heart rate recently? How many steps did I take today to stay healthy? Did I drink enough water? Am I at risk of contagion from being exposed to an infected person?* These are basic but essential health questions that commodity wearable and smartphone devices can promptly answer for a user. Such devices operate as health infomediaries, providing a complete picture of the user and empowering them with better self-awareness and self-care. The near future brings a bold promise of deep health personalization capabilities to consumers, seamlessly integrating with external systems from healthcare organizations and intelligently identifying their optimal care pathway. Yet today, the recent pandemic has left many health and government officials, even everyday consumers, feeling defeated and desperate for better digital health services.

Where, when, and why then did digital healthcare disappoint? *Where* essential health information is missing, hindering critical steps of the decision-making process – in this case requiring technology to support continuous monitoring abilities and data integration of new and legacy systems. *When* not everyone comprehends the crucial messages or experiences the benefits of a health service – in this case requiring the promotion of health literacy, elimination of health disparity, and support for health equity. *Why* it disappoints leads to the one painful truth that digital health could have better assisted professionals in service and mitigated patients' pain. Our new age demands data-driven healthcare solutions that can support large-scale deployment, increase service access to the masses, and be patient-centric to deliver value-based care.

The orientation of my research is as affirmative as it is critical in fulfilling the long-term vision: **toward transformative digital health** – ***one which offers deep personalization to an individual's health but integrates personal health to drive population and public health efforts***. My dissertation and research continuation, hereafter, are aptly positioned to respond to this vision. Lying in the intersecting sub-fields of Mobile and Ubiquitous Computing, Artificial Intelligence (AI)/Machine Learning (ML), and Human-Computer Interaction (HCI), I pursue these investigations through active intra/inter-institutional collaborations among experts in Education, Psychology, Organizational Behavior, and Biomedicine. My research, centered on the three themes below, has been published in top-tier conferences and journals such as ACM IMWUT, CHI, CSCW, and TSAS.

1. **AI/ML-driven mHealth Systems:** This body of work involves developing highly accurate health monitoring solutions by employing different AI/ML techniques and commercially available sensors. In developing these systems, my research seeks to empower everyday digital users with accessible health information and support long-term monitoring at a low cost and with minimal privacy intrusion.

2. **Social Behavioral Modeling and Analytics:** The central focus on sensing individual factors for personal health systems often overlooks the ontological relationships between the user and their social groups/environment, which are critical to one's health. My work in this area employs computational methods to model social groups and analyze their changing interactions as key predictors of health.

3. **Emergency Response and Assistive Technology:** My research thus far has addressed modeling and analyzing everyday human behavior, which will benefit a broad class of users. However, it is equally essential to develop systems that can support unanticipated medical situations and help the underserved population. My investigations in this area consist of repurposing existing digital systems for pandemic preparedness and designing technology for children and elderly.

1 AI/ML-driven mHealth Sensing

The ubiquity of smartphones gives life to new mobile health (mHealth) solutions. Consumer wearables have also shown feasibility in mHealth using wristbands, smartwatches, earbuds, and rings. However, users' failure to continuously wear a device or run a dedicated mobile application can affect long-term monitoring. By employing various AI/ML techniques, my work investigates passive WiFi sensing as a promising modality to support longitudinal and population-wide health monitoring capabilities. It explores ways of replacing dedicated sensor systems that measure key health predictors with commercially available sensors to empower everyday digital users with similar information at low cost and with minimal privacy intrusion.

Passive WiFi Sensing for Personal Health [1], [2]: *SleepMore* [1] and *WiSleep* [2] are sleep prediction systems built with large-scale deployment abilities via passive WiFi sensing to support longitudinal and population-wide monitoring. Specifically, passive WiFi sensing is a network-centric approach where WiFi logs of network events generated by a user's smart device are collected directly from the WiFi infrastructure, bypassing any client-side participation for data collection. Unlike data collected directly from smartphones and wearable sensors, network event data is coarse-grained. The decision to utilize passive WiFi sensing is based on WiFi infrastructures being widely available and highly accessible within indoor environments, especially homes, where everyday users are almost guaranteed to spend their nights. I developed *SleepMore* detection model using a supervised learning technique and trialed the system among participants in campus residences and private homes. In contrast, our development of the *WiSleep* model using an unsupervised learning technique is to achieve a similar prediction without training labeled data. The utilization of varied AI/ML techniques is based on a concrete understanding of the data set and problem formulation within reasonable scope and time. Both systems can accurately predict nocturnal sleep duration every 24 hours, comparable to commodity wearables. *SleepMore* and *WiSleep* can guarantee ***longitudinal and scalable monitoring at low cost*** for as long as user devices are connected to their WiFi.

Mobile Sensing for Environment Safety [3]: External factors such as environmental pollutants can significantly impact one's health. We expanded our mHealth efforts by employing mobile sensing to promote healthy air among everyday users. In the wake of the 2021 economic reboot from COVID-19, as schools reopen and employees return to work, these indoor environments can be at the highest risk of airborne contagion. Reducing the risk of contagion would mean improving indoor ventilation; one way is to increase the airflow rate, especially in crowded places. Typically, facilities management in organizations measures the airflow rate through dedicated installations such as pressure sensors and vane anemometers. While highly accurate, these mechanisms are hard-wired and require installing, calibrating, and commissioning. Further, they are accessible only to facility managers and not to every building occupant. *FlowSense*, the *first* of its kind, "listens" to the sound of moving air through a smartphone microphone and accurately predicts the rate of airflow using a combination of audio signal processing and ML techniques [3]. It exemplifies our effort to develop digital services that can ***empower everyday users with critical public information advantageous to their health***.

2 Social Behavioral Modeling and Analytics

My work continues to address the gaps in mHealth research on technologies for mental health. Specifically, psychiatric studies report mental health as being caused by a complex interplay of external factors apart from the user. The emphasis on accurately sensing individual characteristics of one's health often overlooks the ontological relationships between the *user* and their *social groups/environment*. My contribution includes investigating the impact of social behaviors and their changing patterns on mental health over extended observations. Further, the criticality of measuring social attributes as part of health motivates my work to design detection mechanisms that can more accurately and efficiently determine social groups and their contextual influences.

Social Determinants of Health [4], [5]: As part of my dissertation, I developed *StressMon*, an ML-driven stress-depression detection system [4]. The system operates based on employing passive WiFi sensing to infer students' activity states and mobility trajectories that approximate their routine and interactions on campus. By recording each user's activities on campus, the system ascertains changes in their behavior in reference to themselves and the people around them. Findings from evaluating *StressMon* among more than 150 college students found qualitative and quantitative evidence of social factors affecting their stresses, specifically as a result of working in groups. I continued to investigate the stability and cross-lagged effects of *social identification*, defined as the degree to which individuals perceive themselves as part of an in-group [5]. My analysis found individuals are more likely to elicit affective reactions when receiving little social support or experiencing high workload and burnout.

Now more than ever, "collaboration" has become second nature in professional and educational settings, capitalizing on expertise and perspectives from others. But collaboration remains elusive and frequently disruptive, affecting team-level functions and, worse, individual health. This space in social behavior analytics requires more investigation to ***understand how people can draw on their groups to maintain and enhance health***. Such findings also prove why ***technologies must be able to adapt to changing human behavior and capture the interplay between individuals and their social structures.***

Dynamic Group Modeling [6]: That being the case, the second track explores computational methods for group modeling. The plethora of group modeling approaches driven by different sensing modalities can approximate real-world social interaction attributes such as activity type and group size. While these attributes can help explain the context in which the group interaction occurs, existing approaches lack the preservation of historical and temporal-based interactions over time to continuously revise snapshots of an evolving group. We proposed *W4-groups*, a heuristically-driven group modeling approach using mobility trajectories to capture the long-term representations of *who-what-when-where* in a group based on repeated user colocations and their variances over time [6]. The long-lasting nature of users in their dedicated sets of the environment (e.g., students on campus, employees in the office) requires behavioral health management systems to monitor their progression over extended periods. Similarly, the social interactions within their environments are subject to changes - in frequency and degree of relationship. By accounting for the long-term dependencies within and among users, the system can ***more definitively distinguish groups with varying degrees of relationship.***

3 Emergency Response and Assistive Technology

My research above has contributed to developing data-driven health systems that identify everyday human behavior and routines. While such solutions benefit a broad class of people for day-to-day usage, the functions might not be relevant in situations disrupting standard behavior, such as the recent pandemic. Further, these functions might be less suitable for users with disabilities, especially if they face restricted interactions and routines. My work explores repurposing the systems above for pandemic preparedness and discovering better system designs for children and the elderly, who depend on a caregiver.

Pandemic Preparedness [7]–[9]: While Singapore was examplar in spearheading public health efforts for disease containment, larger countries continued to struggle with asserting these restrictions. For many of these countries, digital contact tracing held so much promise but failed to deliver. The one issue with this service is the strong assumption that users are willing to share their most personal data from their most personal device for the greater good. Worsened by the lack of trust in government bodies and technology companies to handle sensitive information, this digital health piece did not do much good. My research contribution in this area started with an investigative study on *which* critical information users are willing to share through *what* modality and *how* they influence user trust *when* outbreaks with different disease transmissions occur [7]. This study sheds light on the impact of socioeconomic status and domestic characteristics as facilitators in accepting such an effort, thus placing importance on the outreach among populations with lower education. Further, it provided quantitative evidence into the potential of medical health records in coordination with public health personnel as a modality of sharing information. These findings brought to fruition a swift improvisation for a strategic technological solution to assist public health officials with obtaining risk exposure reports and everyday users with staying safe at minimal privacy risk. Accordingly, a forged collaboration between local and overseas institutions generated our response to makeshift the inner workings of my passive WiFi sensing systems for indoor contact tracing. *WiFiTrace* is the *first* network-side contact tracing method built for monitoring user movements and co-occurrences of people in dedicated indoor spaces without any client-side application [8]. Operating in parallel is the comprehensive analysis of a system like *WiFiTrace*, in its impact on control policies [9] for public health practice.

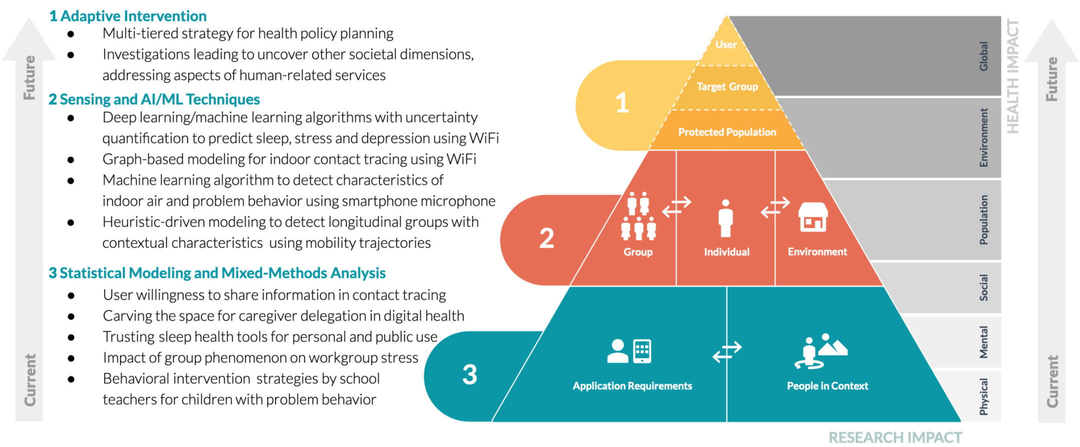
Health Management for People with Disabilities [10]: Ultimately, improving and maintaining health is every individual's most elemental instinct. However, pursuing this natural endeavor understandably seemed too much to bear – for the dependant, untrained dependee, and the underserved population. How should a digital health resource operate for those with debilitating conditions and those helping with a heavy heart? One example of my research is the study on children with neurodevelopmental disorders managing their problem behaviors. A particularly constructive element of this research was working with Special Education teachers to design *WatchMe*, a proof-of-concept system that helps children manage their behaviors independently. I evaluated these notification designs in-the-wild on children formally diagnosed with Autism Spectrum Disorder, Global Developmental Delay, and Down Syndrome [10]. An ongoing work with regional experts in the public health domain includes understanding how we can better enable caregivers to fulfill their medical, legal, and digital delegation duties for dependent adults with cognitive and physical limitations.

On the whole, technology solutions must deliver appropriate functions to support the intended stakeholders. However, unexpected and vulnerable circumstances can hamper the success of digital health systems in serving their purposes and providing critical health knowledge. It is in this vein that my research ***incorporates human-computer interaction practices to discover how to best design and operationalize both human and technological functions.***

Where Do We Go From Here? Computing for Community

Human-centered digital healthcare systems are still in their infancy, with consumers recently embracing technologies that can provide basic health information about their activity and physiological status. Beyond providing personalized care are strong potentials supporting the bolder promise of a fully connected digital health ecosystem, combining the essence of personal health, population health, and public health under one digital roof. Therein lies the system and application challenge my current efforts sought and future research will continue to address. Figure 1 illustrates my research adopting a bottom-up approach to developing health systems. In what follows, I outline some of my research endeavors in the near future.

Figure 1: Bottom-up approach research on health impact for future work



Adaptive Intervention: An immediate next effort is to assemble the adaptive intervention component to complete a full circle monitoring system, which accurately detects and intervenes in a particular health situation. Each of my research projects is uniquely positioned to orchestrate a multi-tiered strategy for health monitoring, intervention, and policy planning. For example, the large-scale sensing systems, *SleepMore, StressMon, and WiFiTrace*, fundamentally sharing the same deployment standards, are intended as sub-components to a scalable solution for on-campus health and behavioral risk surveillance. Depending on user consent and permission grants, these systems can facilitate a needs-based tiered model where aggregated and anonymized analyses can benefit public health interests. At the same time, deanonymized fine-grained health derivations can personally help individual users.

Healthy Smart Cities: As communities around the globe are on the front line of creating smart cities, the success of creating a healthy smart city necessitates tight integration and sustainability of health and other human-related services, including the environment, public safety, and transportation. My current research uses AI/ML techniques to predict user behavioral states for health outcomes. However, these same sets of behavioral states remain relevant across the interdisciplinary domains above and will demand further exploration of prediction modeling approaches. An example is an effort to achieve a net-zero carbon transportation future. Prior work found strong associations between carbon footprint and users' mobility. I hope to bring this research topic further by clarifying the impact of low-carbon mobility on users' health assessments. Such findings are necessary to move beyond traditional health promotions (e.g., walking versus driving) and toward establishing a holistic health program that can enhance the complexity of dynamic associations across biological, behavioral, and environmental outcomes.

Computing for Critical Perspectives: When we began to embrace information and communication technologies (ICT) as part of our lives, the critical engagement differentiating levels of access and utilization of ICT was termed the "digital divide." Now that digital technology is synonymous with our lives, this engagement has shifted focus to its usage in driving debate-provoking actions by individual users and target groups. The rising interest in topics interrogating controversial racial, social, political, and ethical perspectives has led to urgent attention on "critical computing" in the CHI research community. These pressing current events have become more entangled with harnessing healthy social development. My existing research studies have yielded brief qualitative insights into power inequality, social discrimination, and conflict as stress in workgroups. Moving forward, I hope to pursue deeper investigations on how digital technologies and technology-oriented practices perpetuate and facilitate critical end-user actions. I believe the technological functions achieved in my research at present can strategically adapt to such topics as they have intertwined with the *group* and *environment* contexts that both influence and are influenced by the *user*.

References

[1] C. ZAKARIA, G. Yilmaz, P. Mammen, M. Chee, R. Balan, and P. Shenoy, "Sleepmore: Inferring sleep duration at scale via multi-device wifi sensing," *To appear in the Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT)*, 2023.

[2] P. M. Mammen, C. ZAKARIA, T. Molom-Ochir, A. Trivedi, P. Shenoy, and R. Balan, "Wisleep: Inferring sleep duration at scale using passive wifi sensing," *Under major revisions for the ACM Transactions on Computing for Healthcare (HEALTH)*, 2023.

[3] B. Chhaglani, C. ZAKARIA, A. Lechowicz, J. Gummeson, and P. Shenoy, "Flowsense: Monitoring airflow in building ventilation systems using audio sensing," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT)*, vol. 6, no. 1, pp. 1–26, 2022.

[4] C. ZAKARIA, R. Balan, and Y. Lee, "Stressmon: Scalable detection of perceived stress and depression using passive sensing of changes in work routines and group interactions," *Proceedings of the ACM on Human-Computer Interaction (CSCW)*, vol. 3, no. 37, pp. 1–29, 2019.

[5] C. ZAKARIA, Y. Lee, and R. Balan, "Detection of social identification in workgroups from a passively-sensed wifi infrastructure," *Proceedings of the ACM on Human-Computer Interaction (CSCW)*, vol. 5, pp. 1–19, 2021.

[6] A. Atrey, C. ZAKARIA, R. Balan, and P. Shenoy, "W4-groups: Modeling the who, what, when and where of group behavior via mobility sensing," *In review for the Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT)*, 2023.

[7] C. ZAKARIA, P. S. Foong, C. S. Lim, P. VS Pakianathan, G. H. C. Koh, and S. T. Perrault, "Does mode of digital contact tracing affect user willingness to share information? a quantitative study," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*, pp. 1–18, 2022.

[8] A. Trivedi, C. ZAKARIA, R. Balan, A. Becker, G. Corey, and P. Shenoy, "Wifitrace: Network-based contact tracing for infectious diseases using passive wifi sensing," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT)*, vol. 5, no. 1, pp. 1–26, 2021.

[9] C. ZAKARIA, A. Trivedi, E. Cecchet, M. Chee, P. Shenoy, and R. Balan, "Analyzing the impact of covid-19 control policies on campus occupancy and mobility via wifi sensing," *ACM Transactions on Spatial Algorithms and Systems (TSAS)*, vol. 8, no. 3, 2022.

[10] C. ZAKARIA, R. C. Davis, and Z. Walker, "Seeking independent management of problem behavior: A proof-of-concept study with children and their teachers," *Proceedings of the 15th International Conference on Interaction Design and Children (IDC)*, pp. 196–205, 2016.