Research Statement
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I am committed to pursuing technological applications to solve problems in healthcare today, whether through creating systems to train future clinicians, or creating systems that collect and monitor information to ensure people’s long-term wellness. With the rapidly aging population of the United States and more than half of Americans suffering from chronic disease, it is more imperative than ever to develop efficient and effective technical solutions that help meet the growing needs of healthcare. This is a promising and important time for innovative digital technology which can help meet these needs by keeping people safe in their homes at all stages of life, and keeping them aware of pertinent issues for health and well-being. Throughout my academic research, my focus has been to work together with professionals of many disciplines to create systems that function effectively in the real world, and that address and solve compelling real-world problems. Through solving these problems, I have found opportunities to target core computer science issues. One such area is the simplification of mobile-to-cloud system design into unified programming models. Secondly, there is opportunity to create new machine learning approaches that consider the complexity, ambiguity and noisiness of real world data.

Dissertation work

Assessment and treatment of mental health problems is often hampered by a lack of objective data to corroborate patients’ retroactive self-reports. To address this need, I led the development of a smart home system called Empath that unifies data collected from a variety of sensors, including body weight scales, bed sensors, motion detectors, microphones, and touchscreen devices for patient questionnaires. Data collected from these various sensors can be used to track patterns and routines about the activities of daily living, sleep quality, body weight changes, and mood; any concerning trends will trigger an alert to a caregiver. Empath has the capability to easily integrate new sensors, so it can be used to monitor not only depression but also many other mental conditions and wellness concerns. Empath is unique because it uses a mobile-to-cloud architecture that makes it easy to deploy the system into homes and get access to the data. Different assortments of sensors can be integrated, and the data processing configuration can be customized for the aims of particular scenario, because is defined by a set of discrete processing modules.

One particularly unique feature in the Empath system is the ability to continuously track who is speaking in each room, as well as to estimate the mood state when that person is talking. I built a distributed microphone system called Resonate that runs on top of embedded devices to collect ambient sounds from rooms, perform signal processing and feature extraction, and finally perform classification on the sound clips. One particular technical challenge was being able to perform accurate classification in real rooms in the presence of acoustic distortion such as reverberation. My approach was to use a physical model to simulate how various different speakers would sound if placed in each of various rooms. The result was used as input to a classifier that performed close to baseline performance.

Most research projects focused on health monitoring are testbeds and have not been used on real patients. However, Empath has left the test bed and has begun to be employed for real clinical studies. The University of Virginia College of Nursing is currently using Empath for two ongoing studies since 2012. The first monitors people who suffer from epilepsy to see if complementary or alternative therapies can lower stress, improve sleeping
quality, and decrease total number of seizures. While the subjects undergo 8 weeks of training in reflective exercise, Empath continuously reports the quality of sleep and nocturnal seizures using its bed sensors. The second study investigates the relationship between nighttime incontinence episodes, sleep restlessness, and vocal outbursts for those who have Alzheimer’s disease and uses the sleep sensors, wetness sensors, and microphone sensors. The result could help improve the well-being of both people who have Alzheimer’s disease and their caretakers. Empath has also received attention from various assisted living care companies who are interested in licensing contracts to use this technology in new homes they build. Finally, Empath has received positive publicity as it was spotlighted in the January 2012 issue of the MIT Technology Review. Much of the hard work of creating this system earned me the Outstanding Graduate Research award in the Computer Science department for the 2012-2013 year.

Other Projects

In addition to Empath, I have co-authored works with others in our University of Virginia research team as well as with Microsoft Research. One such project, the MusicalHeart smartphone app, is a biofeedback system which indirectly controls heart rate by tailoring song selections to the current or desired activity level. The smartphone uses a SEPTIMU, an earbud equipped with an accelerometer and gyro, to measure activity level and a microphone that can sense the pulse of the wearer. The app adapts and ‘learns’ the response of the heart rate when the user listens to different music. This work has received much publicity and was highlighted in the Economist and Wired magazine.

The second project, called Auditeur, provides a set of tools to simplify the addition of sound recognition into smart phone apps. The API allows the developer to register a particular sound event type, such as a cough or a car horn. Once the sound has been registered, the smartphone instantiates the necessary acoustic processing modules including signal filters and feature extractors, and wires these modules together to extract the necessary features needed for classification. The phone then captures, processes, and classifies acoustic events locally and efficiently. The Auditeur platform is backed by a cloud service that stores user-contributed sound clips to generate an energy-efficient and context-aware classification plan for the phone from a large number of similar sound clips. The Auditeur system uses a similar system of classification that is used in the Empath system for speaker identification and mood detection.

One of my earlier research projects, MetroNET, is an application that illustrates collaborative data sharing on the World Wide Web. First, our sensors gather data about pedestrian foot traffic in front of and into stores, and this data is subsequently made available online to shopkeepers. But in addition to just the shopkeeper, the data can be used by city planners, other shopkeepers, or residents of the city. MetroNet is an application through which we study fundamental problems of sharing data on the Web, such as search, data fusion, and privacy. It was one of the first applications to expose sensor data through a REST web service through an abstraction called a StreamFeed. The work appeared in the Internet of Things 2008 conference, and the basic concept laid the foundation of the Empath system.

For my undergraduate research, I was a part of a small team of two graduate students working on a two-year “virtual patient” project. Medical communication skills are generally taught in later stages of medical school using standardized patients, or actors that pretend to have a certain disease or medical condition. My team built a virtual patient to augment traditional standardized patients so that medical students have the chance to practice a greater variety of more patient scenarios. The system employed a conversation engine, which I developed from working with a medical student to elicit a script for acute appendicitis. Using the steps of a differential diagnosis, I was able to create a conversation engine that could recognize typical questions in a probabilistic fashion to match
them with appropriate responses. The system also integrated nonverbal communication, since the system used cameras to recognize gestures such as pointing to different parts of the body, and could respond with similar animations. I left the project upon graduation, but the system we designed has had tremendous success and has evolved into a company called ShadowHealth.

Future Work

In the future, I would like to start expanding my interests to other health applications such as building assistive technologies for people with disabilities, or tracking and managing chronic diseases. Currently, I am working on two mobile computing projects focused for the Blind. The first uses 3D spatial audio to train someone to navigate through new building spaces by giving specific audial cues about the existence of a wall, appliance, or door. It also has the ability to use speech recognition to route a path to a desired room or object in the building. The Android-based app uses stereo and attenuation to give the user clues about where that particular object is located. I have formed interactions with the Virginia Rehabilitation Center for the Blind to run a user study on this work. The second project aims to add sonar technology to handheld devices for the first time, using the onboard microphone and speaker. By measuring the time to flight for the emitted pulse and when it is received, we can estimate the distance to an object. We use other sensors on the device to get additional information; for instance, the temperature sensor on the phone can be used to give more accurate speed of sound calculation which in turn yields higher accuracy. Also, we use the orientation sensor (magnetometer) with the distance estimates to map the room’s geometry. We have shown that we can obtain reliable distance estimates to help someone avoid obstacles and also be able to navigate through a space.

I would also like to expand the sound recognition platform of Auditeur and Resonate to focus on improving safety in the home, especially for the hearing impaired. Using the same type of features we used to detect who is speaking, we can extend them to detect dangerous or alarming sounds such as a breaking window, a crackling fire, or screaming. There is a rich area of technical challenges to be addressed when using a microphone as a sensor. The presence of noise, reverberation, attenuation, and overlapping sound signals all make classification very difficult in real environments. I would like to use my experience in acoustic sensing to create an integrated acoustic processing system that would combine multiple classifiers, matched-condition training, blind source separation, and new signal processing algorithms into a general-purpose sound sensing system.

These are just a few ideas I have for ways to expand my current research. As I am focused on addressing real life problems and engaging in cross-disciplinary projects with people in the field, I intend to also immediately consult the local hospital and healthcare providers in order to get ideas about what the biggest issues they face in the field. This will enable my research team to identify projects that could have an immediate and practical effect in the community.