1-2018

IoT-Enhanced Human Experience

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The two articles in this special section represent ongoing Internet of Things applications in the context of Europe trying to make solutions usable to people in daily times.

Modern societies are seeing an unprecedented surge in the number and range of devices deployed and used in day-to-day applications, including mobile phones, tablets, wearable devices, and other connected sensing and actuation devices, collectively referred to as the Internet of Things (IoT). By one estimate, by 2020, 50 billion such devices are expected to be deployed. Such a massive number of IoT devices will be continuously or periodically making the data they generate available on the Internet. They represent an unprecedented opportunity to develop contextually intelligent applications with far-reaching societal implications. They can deliver fine-grained services in various areas such as health, fitness and wellbeing, manufacturing, transportation and logistics, disaster coordination, sustainability and the environment, and human development and social good. These intelligent applications and services, however, could also pose privacy, security, and trust issues and risk a person's safety.

Consider a couple, Alex and Bela, living together for a period, taking care of themselves and each other's health as they proceed in their life from their early 20s to 70s. When they got married in the 1960s, they were getting annual physicals done by a family physician whose findings and vital readings were shared with them as paper reports. They kept some and lost some (possibly due to shifting homes over time). As they turned over 50 in the 1990s, and reports of some medical tests became digital, they started accessing them online at the portal or over email. Collating all these reports (paper and digital) to get a full health picture (for themselves or their doctor) meant printing all the reports on paper. If they changed insurance providers or doctors, they had to reproduce the full status so that the new providers could make accurate decisions without requiring new, unnecessary, and costly testing. Moving into their 70s in the 2010s, they have health data from annual checks as well as more periodic monitoring devices like fitness trackers (per second) and blood pressure monitors (daily). It has become very hard for them to put all their information together to show a doctor or review themselves. They rely on an insurance provider or a doctor network to do it, but as a side effect, they are now locked into a specific health network that has their digital data. The personalized data generated under their watch, also called patient-generated health data (PGHD), don't make it into the clinical system automatically, and the busy clinician may not may have time to look at the data on the patient's device, and may rarely incorporate the information gleaned from that data into clinical records. Furthermore,

Published by the IEEE Computer Society
1089-7801/18/$33.00 ©2018 IEEE

if the healthcare provider suffers a security breach, Alex and Bela may lose all their health data except those that they have paper copies of.

But Alex and Bela do not live in isolation from their family and friends—they have a social circle of people who care for them but do not expect monetary benefits in response. A prime example of this is children who need access to their parent's health data so that, when called upon or on their own volition, they can interact with health providers on behalf of their parents. Most IT systems in healthcare involving doctors, insurance, and patient history do not allow social sharing of selective data based on the patient's care needs. This is one of the many care-giving challenges that people expect in an IoT-enhanced real world.

Alex and Bela also do not live in isolation from their environment, which affects their health. If they lived in Flint, Michigan and their water was polluted by the decisions of others,[1] all stakeholders in their health would need to understand what they could do reactively and proactively. Furthermore, weather data could help them tune their daily habits, given their health conditions and the water situation of their neighborhood. In the vision of *computing for human experience*, we also talk about broader interaction of a person and IoT-collected data relevant to a person's interests or activities, and use of online infrastructure of specialized services and experts that work in concert to improve human experience (e.g., the quality of life or personal or business decisions).[2] Thus, the IoT has a major role to play to improve and transform our lives.

An IoT that captures primarily the data of the physical world (e.g., physiological data in the case of health-related activities or applications) is increasingly being complemented by online data and knowledge and data and experiences shared on social media to provide physical, cyber, and social big data that are relevant to improving human experience.[3] For example, an ongoing effort on managing asthma combines a patient's physiological-data-related feature (a peak flow meter for lung functioning or a Fitbit for activity levels), physical surrounding (indoor air quality, temperature, humidity, etc.), external environmental data (the air quality index and allergens in the environment, including pollens and mold), and structured information extracted from the physician's clinical notes for the patient. These multimodal data enable identification of personalized correlations (e.g., high ragweed leads to allergy and later chest tightening when not treated) for a patientThese data, combined with background medical knowledge (here, an asthma control protocol on how symptoms are related to asthma control levels and which medications are generally prescribed for a patient for a given asthma control level) and with information extracted from the patient's clinical records serving as a baseline (e.g., a doctor's guidance on which medication to take when certain symptoms present), allow a patient to continue the self-appraisal of his or her medical condition. These efforts will then evolve into more sophisticated healthcare solutions—such as self-management (e.g., assisting the patient to better track a physician-specified care plan for the desired outcome), prevention, and disease progress predictions.

Solving the challenges of exploiting the IoT and related diverse data to enhance human experience will need existing and new techniques from many subdisciplines of computing to come together, apart from those in target domains. Just focusing on IoT data, the challenges include sensors for data acquisition, data storage and integration, insight generation via AI (machine learning, natural-language processing, the Semantic Web, and reasoning), security, networking, and energy management. Finally, issues related to the humanities also need attention: psychology, sociology, the user experience, and the ethics of AI-augmented decision making.

The collected data need to be analyzed for insights that will inform or drive actions affecting human activities (and hence human experience). This analysis should be comprehensible and reproducible by the involved users. For example, both the raw data and processed insights have to be secured and made traceable to gain the trust of humans. For any insights from machine learning that are generated, the techniques may be called to explain its outputs. Usage and acceptance of insights by humans will drive future waves of IoT devices and consumption of their contextual data. Ultimately, insights from machine learning will become meaningful only if we manage to combine machine precision with human creativity and domain knowledge. Thus, we have to find ways of codifying human knowledge and experience into machine-readable formats such that they become available for incorporation into machine learning.[4]

The IoT will impact human activities and experience, including but not limited to

- individual and community needs—personal and public health, entertainment, and quality-of-life improvement;
- enterprise needs—logistics, procurement, customer engagement and experience, human resources, connected manufacturing, incorporation of customer feedback into the product lifecycle, and products with embedded services such as predictive maintenance;
- smart or connected city and government (societal and environment) needs—energy, transportation, water, and citizen empowerment and engagement; and
- human, social, and economic development needs—including crisis response and coordination, improved living standards, and improved utilization of community and natural resources.

The two articles in this special section relate to two of the most important domains or application areas: energy and healthcare. The article "IoT-Enhanced User Experience for Smart Water and Energy Management" reports on the authors' experience at developing and deploying IoT-enabled solutions and engaging people based on outcomes. Specifically, the developed systems relate to water and energy management in different types of buildings: airports, homes, offices, schools, and universities. The authors discuss system capabilities that they found enhances user experience and awareness. The second article, "Internet of Things for Dementia Care," reports on a project in the UK on the role of the IoT for managing dementia patients. Reporting on a regulated domain impacting people directly, the article discusses the architectural decisions taken to address issues like data governance, data integration, security, and usability.

CONCLUSION

The two articles represent ongoing IoT applications in the context of Europe trying to make solutions usable to people in daily times. We hope they give impetus to more such efforts around the world.

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