Research Assessment Exercise 2020

Impact Case Study

University: The Hong Kong University of Science & Technology

Unit of Assessment (UoA): 13 - computer studies/science (incl. information technology)

Title of case study: IoT-based healthcare exploiting novel sensing and asymmetric communication system

(1) Summary of the impact

Chronic diseases are a serious social problem and significant public burden because of the large patient numbers and high medical costs. The Internet of Things (IoT) has the potential to revolutionise existing healthcare service models and lessen this burden, as it offers the means to greatly improve disease prevention, intervention and long-term management. We have developed intelligent IoT sensing and analysis technologies that effectively monitor the user's vital signs and health-related behaviours. Our remote health monitoring system has benefited more than one million patients and enabled an end-to-end healthcare service model for chronic diseases management.

(2) Underpinning research

The efficient communication and sensing capability of smart devices has attracted great attention from both academia and industry as it offers benefits but also raises issues. Professor Qian Zhang's research group focuses on some of these issues.

Efficient wireless communication for IoT devices – The explosion in the variety of IoT devices including wearables and sensors has heightened the demand for efficient communication. Wi-Fi has become a contender for satisfying this demand as its coverage is ubiquitous. However, high-speed Wi-Fi brings little benefit to low-end devices and instead becomes an overwhelming energy burden. Meanwhile, the proliferation of IoT devices means that future connectivity is envisioned to be massive. Thus, Wi-Fi for IoT devices should be not only low power but also spectrum efficient. We argue that existing Wi-Fi transceivers are designed for symmetric nodes. This assumption no longer stands for IoT applications, where the Wi-Fi Access Point (AP) is much more powerful and almost energy-unconstrained compared to IoT devices.

We designed Sampleless Wi-Fi, a novel solution that allows energy-constrained devices to scale down their sampling rates by exploiting the time shift effect at receivers to create new constellation diversity.[1] To further harvest the asymmetry between AP and IoT, we developed a method whereby IoT devices transmit uplink packets using the lowest power while pushing all the decoding burdens to the AP side.[2] To reduce the severe contention due to the huge amount of IoT devices, we created Carpool, a system that enables in-time response to concurrent requests from multiple users by allowing each downlink transmission to carry payloads for multiple receivers.[3] As fixed channelization configuration in today's wireless devices becomes inefficient in the presence of growing data traffic and heterogeneous devices, we developed the first frame-level wideband spectrum adaptation scheme and prototype to improve the system throughput.

Ubiquitous behaviour sensing to enable a new type of healthcare – Human-centred sensing attempts to achieve a comprehensive assessment of people's health conditions, living habits and even mental states, through monitoring their sleeping quality, dietary information, daily routines, etc. Numerous healthcare applications could benefit from advanced human sensing systems including elder-care, dietary management and fitness guidance.

Leveraging wearables, we built several reliable and practical human sensing systems. We designed a real-time automatic sleep-scoring system which can detect sleep stages and occurrence of sleep apnoea in real time. Pursuing this direction, we developed the first smart pillow system for the detection and alleviation of sleep apnoea. The smart pillow's shape and height automatically adjusts to alleviate the apnoea.[4] We further designed a remote stress monitoring and alleviation system, deStress, which quantitatively assesses user's stress levels and alleviates his/her stress by adaptive respiration-based bio-feedback.[5] To bring practical dietary monitoring into daily use, we designed

two systems: we integrated an electromyography (EMG) sensor into glasses to measure the muscle activity of the temporalis to detect intake-related events; and we created a new utensil, Smart-U, that recognizes meal composition during the intake process by leveraging the fact that light spectra reflected by foods are dependent on the food ingredients.[6]

(3) References to the research

1. W Wang, Y Chen, L Wang and **Q Zhang**, Sampleless Wi-Fi: Bringing low power to Wi-Fi communications, *IEEE/ACM Transactions on Networking (ToN)*, Vol 25, Issue 3, June 2017, pp1663–1672
2. W Wang, S He, L Yang, **Q Zhang** and T Jiang, Wi-Fi Teeter-Totter: Overclocking OFDM for Internet of Things, *IEEE Infocom 2018*
3. W Wang, Y Chen, **Q Zhang**, K Wu and J Zhang, Less transmissions, more throughput: Bringing Carpool to public WLANs, *IEEE Transactions on Mobile Computing (TMC)*, Vol 15, No 5, pp1168–1181, May 2016
4. J Zhang, **Q Zhang**, Y Wang and C Qiu, A real-time auto-adjustable smart pillow system for sleep apnea detection and treatment, *IEEE IPSN 2013*
5. J Zhang, D Chen, H Tang and **Q Zhang**, deStress: Mobile and remote stress monitoring, alleviation, and management platform, *IEEE Globecom 2012*. **(Best Paper Award Winner)**
6. Q Huang, Z Yang and **Q Zhang**, Smart-U: Smart utensils know what you eat, *IEEE Infocom* 2018.

(4) Details of the impact

Gartner Inc estimates that the number of deployed IoT devices will reach 20.8 billion in 2020. The IoT holds the potential for societal scale impact by transforming many industries, as well as our daily lives. It will revolutionize healthcare and enable a broad range of healthcare applications, from managing chronic diseases at one end of the spectrum to preventing disease at the other. Our research has had an impact in the following areas, and is enabling a new healthcare service model through better sensing and understanding of the user's behaviour.

IoT devices for improved heart rate and sleep monitoring and management – Research suggests that the detection of abnormal heart rate variability as well as sleep/circadian disruption could be valuable markers of vulnerability in the early stages of neurodegenerative diseases. There is therefore a pressing need for longitudinal heart rate variability and sleep monitoring. Working with senior doctors at the People's Liberation Army General Hospital and the Shenzhen People's Hospital, we invented wearable IoT devices that reliably perform heart rate variability monitoring and automatic sleep stage scoring. From the measured heart rate variability, we can detect and derive the psychological stress. We further designed personalized controlled respiration system to alleviate potential stress. Our work received the Best Paper Award in the IEEE Globecom conference. Three patent applications have been submitted.

We also developed a phone-based auto-adjustable pillow system for alleviating sleep apnoea. Sleep apnoea events are detected in real-time by the invented IoT device, and the height and shape of the pillow automatically adjusts to terminate the sleep apnoea event. We conducted a hospital trial on 40 patients over 80 nights, which demonstrated that both the duration and number of sleep apnoea events were dramatically reduced by over 50%. The pillow design was awarded medical equipment certification by the SFDA. An HKUST press release about the system attracted significant public interest and the technology was covered by major media.

Wearable-based and contactless-based dietary monitoring – Dietary monitoring can provide valuable information for disease diagnosis, body weight control, and dietary habit management, and so is welcomed by patients, dieters and nutritionists. Existing solutions either require tedious manual recording or may impede normal daily activities. We designed a pair of diet-aware glasses, with the key idea that when people wear glasses, the temples of the glasses are in touch with the

lower part of the temporalis muscle, one of the mastication muscles. An integrated electromyography (EMG) sensor measures temporalis muscle activity to detect intake-related events. Our glasses provide detailed information on intake schedule, the number of chewing cycles and the broad category of food. To further track what foods are consumed in an unobtrusive and detailed manner, we introduced the Smart-U utensil, a new method for tracking meal composition during the intake process. Smart-U works by analyzing the difference in light spectra reflected by the foods on the utensils (the spectra reflected depend on the chemical properties of the types of foods). Through such analysis, Smart-U can infer which foods are placed on the utensils.
Professor Zhang was invited to introduce this intelligent IoT sensing capability in the Hospital Authority Convention 2018, which was attended by 5,400 clinicians and healthcare professionals, and personally served as the technical consultant for the Hong Kong Hospital Authority.

An innovative new chronic-disease management model leveraging our IoT-based system – Typical chronic diseases, such as hypertension, diabetes or sleep respiratory syndrome, require long-term tracking and management. Utilizing our health IoT devices, and our corresponding data collection and analysis cloud platform, we have been collaborating with Shenzhen People's Hospital since 2012 to help it take the lead in establishing the country's first cloud-based 'networked hospital'.
This networked hospital service model can change the traditional treatment-centric medicare to a health-centric one. In this system, a number of 'health stations' are established to enable vital sign monitoring and health management outside of hospital. These health stations use a variety of our IoT devices with wireless transmission capability, to transmit blood pressure, blood glucose, heart rate variability, pulse, sleep quality, psychological pressure and other physical conditions as real-time data. In 2016 alone, more than 660,000 discharged patients, post-outpatient patients and those with abnormal data from medical examinations were served in this way. Since the networked hospital has been in operation, as of 2017, the total number of users has exceeded 1.14 million.

(5) Sources to corroborate the impact

1. Mr Bingfu Wang, Director of CT (Communication Technology) Lab of Huawei Corporation and Dr Haibo Lin, Director of Collaboration, Huawei Corporation
2. Dr Hong Tao, Director of the Networked Hospital Centre, Shenzhen People's Hospital
3. The Hospital Authority Convention 2018, http://www3.ha.org.hk/haconvention/hac2018/en_index.html
4. Journal article from China Huanqiu website: https://china.huanqiu.com/article/9CaKrnJUxdF
5. Official website of Shenzhen people's hospital: www.169jk.com
6. Official website of Southcn website: http://news.southcn.com/gd/content/2019-06/05/content_187855518.htm
7. SFDA sleep pillow medical equipment certification: http://app1.sfda.gov.cn/datasearchcnda/face3/base.jsp?tableId=26&tableName=TABLE26&title=%B9%FA%B2%FA%C6%F7%D0%B5&bcId=152904417281669781044048234789
8. Patent: US20130157580A, Inventors: Jing Qiu, Qian Zhang, Spectrum Sensing Method, Apparatus, and System (granted) https://patents.google.com/patent/US20130157580A1/en?inventor=Jing+Qiu&oq=Jing+Qiu
9. Patent: US20130010725A1, Inventors: Kaishun Wu, Qian Zhang, Lionel Ni, Transmitting and/or Receiving Data in a Side Channel (granted) https://patents.google.com/patent/US20130010725A1/en?inventor=qian+zhang&oq=qian+zhang&page=9
10. Patent: US10,003,123B2 (USA), Inventors: J Zhang, Z Yang, Q Zhang, Full-duplex antenna and mobile terminal (granted) https://patents.google.com/patent/US10003123B2/en?inventor=zhice+yang&oq=zhice+yang