Guest Editorial: A Roadmap for Mobile and Cloud Services for Digital Health

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1 Introduction

We have entered the Digital Health era. In recent years, we witnessed sharp increase of activities in research, design, development, real-world deployment and evaluation of smart environments, assistive technologies, medical robotics and health telematics systems by employing computing and communication technologies in the health domain [1]. Stakeholders from academic, clinical, and industrial perspectives have been working with end users, family caregivers, and healthcare providers to explore how to properly utilize digital technologies to foster independent living and improve quality of life. With over 76 million of baby-boomers who are "graying" fast in the US alone [2], the "silver industry" will call for advanced research and development endeavor. Digital health will surely become the mainstream paradigm to provide cutting-edge healthcare services to the graying population.

Such a promise is based on the rapid advances in aware computing [3] in the fast-emerging field named the Internet of Things (IoT), where mobile and cloud services are key enablers to foster a new IoT based industry. Now, one of the major concepts of IoT is Internet of Medical Things (IoMT) [4]. IoMT basically includes a large collection of medical devices and applications that connect to healthcare IT systems through online computer networks for monitoring patients, admistering medicine, fetching fitness data, and so on. Oftentimes, devices for IoMT can link to cloud services for the analysis of captured data.

One of the major challenges for the healthcare industry and the government is the prohibitively high costs of healthcare for the average families in the coming years [5]. Computing techniques including mobile and cloud based digital health services have thus become the basis for future healthcare and medicine, in terms of both cost-effectiveness and richness of expanded services to extend the capabilities of hospicals and health clinics.

2 Digital Health and Mobile Digital Health

Digital Health can be described as convergence of digital and genomic technologies with health, healthcare, living, and society to enhance the efficiency of healthcare delivery and make medicine prescription and medical treatments more personalized and precise [6]. ICT technologies in this field are rapidly growing to such an extent that, in 2016, Food and Drug Administration (FDA) in the U.S. officially adopted related technologies in Digital Health [7]. FDA has created the digital health program to encourage and foster collaborations in technologies to promote public health. FDA also released the guidances on the public website related to Digital Health. These guidances are designed to help healthcare providers and medical device makers better understand how FDA thinks about the balance between incurred benefits and risks.

With the advent of big data analytics, Digital Health has also become the cornerstone of precision medicine [8]. The concept of precision medicine, which is prevention and treatment strategies that take individual variability into account, is not new; however, the prospect of applying this concept broadly has been dramatically improved by the recent development of large-scale biologic databases, powerful methods for characterizing patients, and computational tools for analyzing large sets of data [9]. Precison medicine promises to offer "individualized healthcare services," a notion advocated by *Situ* [10], where individual's situation is modeled, monitored and analyzed in order to enable such service provisioning.

However, Digital Health as continuously emerging and evolving area addressing public concerns with the provisioning of nimble and more accurate healthcare would require a functioning business ecosystem in the marketplace. For bridging between the business ecosystem and individuals, mobile devices inevitably play an important role of Digital Health on the cloud, which can be called mHealth [11] or better characterized as Mobile Digital Health (MDH).

Certainly, we cannot develop a system for each individual to fulfill such a vision with appropriate choice of individualized healthcare services, because the difference between individuals largely depends on data types of the activities of daily living (ADL) [12] and what the individual desires to achieve [13] as far as health is concened. Thus, data-directed realization of individualized healthcare/medical services worths the attention of the researchers in Digital Health. The service oriented architecture (SOA) over the cloud is promising for the MDH to effectively handle a large volume of mobile health data. It offers great flexibility and expandability to allow new devices, new data sources, and new data analytics to

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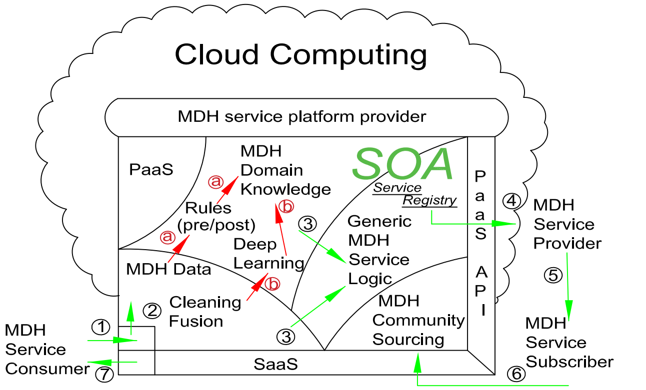

Fig. 1. Service oriented architechture on the cloud for mobile digital health.

be incorporated, and innovative services to be rendered accordingly. In sum, MDH can be largely supported by the modern-day computing infrastructure including Services Oriented Computing (SOC) and Cloud Computing.

3 Business Architecture and Ecosystem

Effectiveness and efficiency for handling potentially very large volume of mobile health data to be collected from mobile devices, and fast, if not instant, feedback to the users on the move will be critical factors to the success of MDH. We envision that the stakeholders of an MDH ecosystem should consist of minimally four major entities. Fig. 1 provides a pictorial view of the architecture, and the corresponding workflow can be described as follows:

1. MDH service consumers must agree to be monitored to provide mobile health data to the service platform.
2. MDH service platform provider (i.e., a Platform as a Service, or PaaS, provider) pre-processes such mobile health data with the techniques of data cleaning and data fusion, among others.
   a. Rules will be extracted from the clean and enriched data like the pre/post conditions [12] as the basic elements of the MDH domain knowledge base.
   b. Through deep reinforcement learning the MDH domain knowledge base will be enhanced.
3. Both preprocessed MDH data and the MDH domain knowledge base will be used by the MDH service platform provider to create generic service logic (algorithms) in order to populate the MDH service registry with an established PaaS API. In this way, an MDH service platform provider can support a wholesome business community. This approach is similar to the Amazon's AWS [13] cloud service provisioning.
4. The MDH service providers will use such an API to gain access to the generic service logic and develop MDH services targeted to the MDH market place.
5. A particular MDH service provider can sell MDH services to the healthcare entities, collectively called the MDH services subscribers, such as doctor's offices, clinics or hospitals.
6. The MDH service subscribers will subscribe MDH services from the MDH service providers meant to benefit their patrons.
7. Throughthe Software as a Service (SaaS) mechanism the prescribed MDH services are finally rendered to the MDH service consumers, i.e., the end users or the patients.

With such a business ecosystem, an MDH stakeholder community is formed. It is also expected that once a stakeholder opts in, the entity will contribute to the community-wide crowd sourcing to contribute medical and healthcare data, e.g., symptoms, diagnoses, prescriptions, privacy safeguarded, for the benefit of the community as a whole.

4 Technology Stack in MDH

In order to enable a MDH ecosystem, a large array of computing technologies must be employed. We can principally divide the useful technologies into four layers, and each layer consist of two levels of sophistication. These four payers are, from the ground up, the Internet of Medical Things (IoMT) & Data/Control Gateway, Learning and Discovery, Mobile and Cloud, Human-Computer Interaction (HCI) and Social Net. We will elaborate each layer in the following.

IoMT and Data/Control Gateway. Basically, the IoMT includes mobile devices, such as mobile phones and smart wristbands, that provides medical/healthcare related to the system through *multimodal sensing*, e.g., vital signs, EEG signals, gaze and gesture, and delivers medical diagnostics and advisory and/or preventive measures to the end-users through *actuation via multi-channels*. Such sensing and actuation mechanisms constitute a data/control gateway that needs to be programmed. As such data can be noise-laden thus data cleaning will be first needed. Moreover, and as they will arrive as big data (volume, velocity and variety), some form of data fusion (time-series if data carry timestamps) will be needed for data analytics.

Learning and Discovery. As human subjects are not static entities and evolve with time while consuming the MDH services, there is a need to adaptively manage the physical and mental dynamics and extreme complexity along the human dimension [14]. Machine learning and the rapidly emerging deep reinforcement learning will be employed to mange the wealth of MDH domain knowledge and gain wisdom in manage human's medical and health situations.

Mobile and Cloud. The prevalent mobile-centric services computing and cloud computing infrastructures and platforms will be leveraged and tailored to the MDH services provisioning. As "data talks" has become the cutting-edge computing paradigm, the MDH service platform owners will play a dominant role in the MDH business ecosystem. In addition to supporting the existing service oriented computing and cloud computing, we expect that there will be two primary functions to be assumed by the service platform providers in terms of MDH, including: 1) enable generic MDH service creation where MDH domain-knowledge-rich data and MDH domain-specific logic wll be bundled together ready for deployment through the PaaS API; 2) foster one MDH community as an organic group to continue seeding and growing the know-hows, mutual benefits, with all stakeholders contributing. As such, there can be many peripheral players (MDH service providers) who will search for applicable MDH generic service bundles in the service registry hosted by the MDH service platform vendor to develop

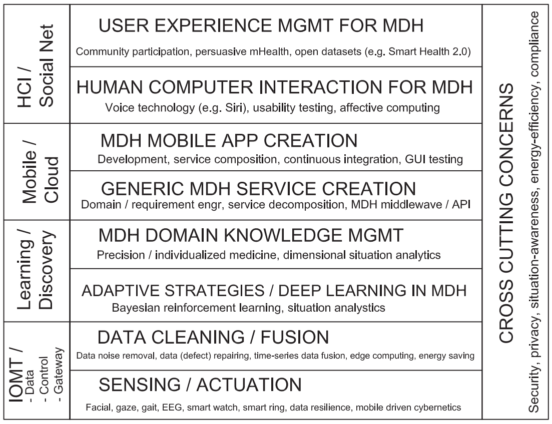

Fig. 2. Technology stack in mobile digital health.

value-added end-user products and services targeted to the healthcare or medical organizations such as hospitals and doctor's offices. As we are aware of, certain pilot concepts of such an envisioned MDH business ecosystem are already in place. For example, MyChart has been deployed to many doctor offices in the US [15], although there is still much to be done to embrace a full-fledged MDH paradigm.

Human Computing Interaction and Social Net. Certainly computing professionals will insist that HCI studies must be engaged to cater positive services to users and enrich user experiences. In the envisioned MDH enterprise, all stakeholders can benefit from everyone else's contribution as a community in order to continuously improve the MDH technologies as time goes. In our opinion, formation of such a social network can be best facilitated by an MDH service platform provider because this entity serves to support many MDH service providers and MDH service consumers; thus, it owns an ecosystem-wide perspective.

In Fig. 2, we also present a list of cross-cutting concerns that cut across all layers of technologies, such as security, privacy, situation-awareness, energy-efficiency and compliance with laws and regulations, e.g., HIPPA in the U.S. [16]. Because of space limitations we will not elaborate into these important yet quite complex set of issues.

Such a publish/subscriber, agent-based mechanism supports three major stakeholders, namely, the service customers (individual users), the service providers (Health IT professionals) and the service subscribers (e.g., health clinic, doctors' offices). The charging or revenue-generating schemes include institutional licenses, individual user's SaaS fees, etc.

Such a system architecture can readily extend its capabilities by adopting pertinent existing and emerging techniques such as brain analytics using EEG/NIRS brainwaves, indoor/outdoor positioning, non-verbal communications, etc.

5 In This Issue

This special section includes three papers selected from the 14th International Conference on Smart Homes and Health Telematics (ICOST 2016) [17] that was hosted for the first time in China by Huazhong University of Science and Technology. The theme of ICOST 2016 was "Inclusive Smart Cities and Digital Health" focusing on the quality of life of dependent people not only in their homes, but also in outdoor living environments, with the aim of improving mobility and social interaction in the city. Researchers in ICOST 2016 discussed on significant and new research and development advances in mobile and cloud services to sustain the human endeavor in Digital Health.

For this special issue, we received high-quality submissions including significantly revised papers recommended by ICOST 2016 for consideration. After rigorous assessment by many dedicated reviewers, we selected only three papers to showcase several important facets of Digital Health. The work ranges from context-aware systems suitable for healthcare providers to the technologies in healthcare applications with wearable devices brought into the people's homes.

In "Adaptable Context-Aware Cooking-Safe System," Rami Yared and Bessam Abulrazak introduce a cooking-safe system. Kitchen safety is a highly important concern for daily living activities. Their cooking-safe system incorporates the detection of risky situations through the measure of physical parameters such as the presence of hot appliances, combustive parameters such as the presence of carbon monoxide. These properties are used to determine the risk severity levels according to the contextual information around kitchen oven. Once the contextual information is gathered using multimodal sensors deployed around the oven, the risk severity levels are automatically assessed using a fuzzy logic based reasoning engine. Conceivably this technology is suitable as an IoT application, albeit only the service-receiving end can be mobile.

In "A New Deep Learning-based Food Recognition System for Dietary Assessment on An Edge Computing Service Infrastructure," Chang Liu and his colleagues looked at an interesting approach, edge-cloud paradigm with deep learning based algorithms, to tackle the food image recognition problem for Digital Health. Nowadays, accurate dietary assessment is very important to assess the effectiveness of weight loss interventions. The authors especially addressed the challenges on both development of deep learning-based visual food recognition algorithms and design of a food recognition system with edge computing-based service computing to overcome the problems, such as unacceptable system latency and low battery power of mobile devices. From the results of extensive experiments with real-world data, the authors found that the deep learning-based food recognition system can achieve three objectives: (1) outperforming existing work in terms of food recognition accuracy; (2) reducing response time that is equivalent to the minimum of the existing approaches; and (3) lowering energy consumption which is close to the minimum of the state-of-the-art.

In "RunnerPal: A Runner Monitoring and Advisory System Based on Smart Devices," Fei Gu and his colleagues introduced a runner monitoring and advisory system called RunnerPal. It is a convenient, biofeedback-based, automated music recommendation system, which utilizes Bluetooth headset, Apple Watch and smartphone to obtain body-sensed data. Running is one of the most important workouts to keep one's body fit. During the running activity, the system attempts in real-time to harmonize the rhythms of breathing, heart beating and striding based on smart devices. The authors proposed a novel approach to calibrate the result by integrating ambient sensed data with a physiological model called Locomotor Respiratory Coupling (LRC), which indicates possible ratios between the striding and breathing frequencies. With the application of PID-based music recommendation from the analysis of the ambient sensed data and runner's contextual information, RunnerPal provides dynamic music suggestions to help the user achieve a target heart rate. In their experiments, one of the promising results was that the system could help runners achieve a target heart rate and maintain a stable running rhythm for indoor/outdoor running 91.6 percent of the time.

6 Research Challenges

Ongoing research to propel more advances in mobile and cloud services for Digital Health will face the following, but not limited to, challenges in a list form:

- Deployment of MDH services to the residents living in the urban or countryside with poor infrastructure or problematic affordability
- Big data collection, processing and analysis via IoMT, supported by mobile/cloud computing
- Participatory telehealth utilizing mobile social media and crowd sourcing
- Coaching and serious gaming for e-Health in the cloud for the aging adults with attitude for or against technolgies
- Genuine human-in-the-loop MDH services capable of instant or fast enough intervention or feedback loop for meeting real-time requirements
- Cognitive technologies across the lifespan and functional abilities with mobile and cloud supports
- Tele-assistance and Tele-rehabilitation for tbe subjects who are determined to "age in place"
- Mobile Health and cloud-based chronic disease management/protective systems/devices against common and emerging infectious diseases
- Context-aware, situation-aware and autonomous computing for digital health
- Wearable sensors and continuous health monitoring with public/private cloud supports
- Cross-cutting issues with security, privacy, situation-awareness, energy-saving and compliance.

7 Outlook

In order to support the development and evolution of the Mobile Digital Health ecosystem as outlined in this article, service integration will play an important role as traditionally fulfilled by various Enterprise Service Bus (ESB) [18], [19] providers. A collective wisdom of major companies is needed to iron out an industry-wide plan, including some form of agreed upon standards and protocols to support MDH. Marketing and deployment of MDH will add another layer of complexity to the prevalent SOA and cloud computing industry. The future MDH market segment to be carved out from the entire digital health market [20] is conceivably large enough to accommodate many players, and it seems advisable for interested entrepreneurs to focus on a niche component of the MDH Technology Stack as the entry into the promised land.

We live in a very exciting world where Digital Health offers a great optimism that we, humans, can live longer, healthier and happier, should more and better innovative healthcare and medical services be created by and for us.

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