Position Paper: Low-Cost Solutions for Home-Based Healthcare

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Abstract— **This paper describes approaches to the use of wearables and related monitoring and diagnostic tools to glean and present data to patients and their caregivers in the form of Personal Health Dashboard. Raw data from devices such as fitness watches, blood glucose and blood pressure monitors can be analyzed by machine learning algorithms ensembles over the cloud or at the edge, and the resulting patterns can be presented to allow for actionable responses. The advent of low-cost computational, sensing, monitoring and diagnostic tools allow for cost-effective solutions that can have wide adaptability. The paper draws from prior and ongoing research conducted by the team to present these positions in the advancement of healthcare.**

Keywords— Frugal Engineering; Data Analytics; Machine Learning; Healthcare; Dashboarding

I. Introduction

The healthcare needs of different cohorts vary greatly. Technology has become a great tool in the advancement of healthcare, both in the care of patients with health conditions as well as in the areas of health maintenance, as shown in Fig. 1. Health conditions are not always diseases. One instance of a condition where monitoring may be beneficial is during pregnancy through the monitoring of the mother, the fetus or both [1]. In certain instances, such as with gestational diabetes, the mother has both an acute and a chronic need, both of which can be satisfied by technological solutions [2].

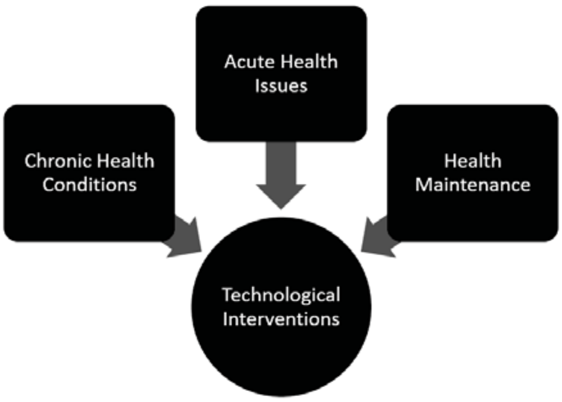

Fig. 1. Variances in healthcare needs requiring technological interventions

Large-scale incidents such as the COVID-19 coronavirus pandemic may create new needs among various cohorts [3]. Similarly, natural and manmade disasters can also necessitate temporary or permanent healthcare needs [4]. Healthcare needs include information provision through the monitoring of health parameters, diagnoses, help identifying medical professionals and services and therapeutic assistance with medication, nutrition and diets, exercises as shown in Fig. 2. Rehabilitative at-home care is another area where technological solutions can be fruitful to the patients and medical professionals.

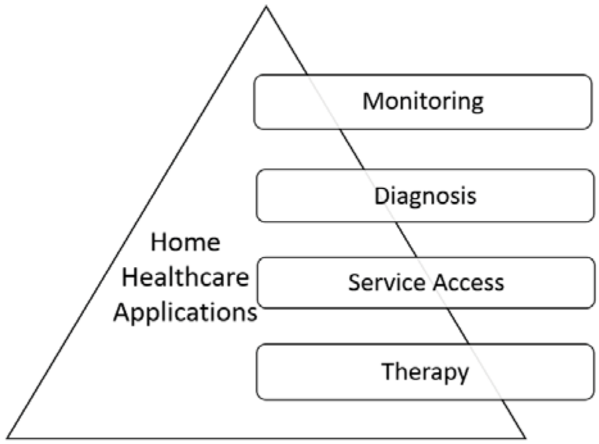

Fig. 2. Types of Home Healthcare Applications

A. Technologies for Home Healthcare

Technological solutions available for the generation of home healthcare include the following state-of-the-art paradigms. In healthcare parlance, therapies that offer the highest quality of care and ensure the largest possibility for success are referred to as the gold-standard.

1) Telemedicine for various healthcare needs [5]

2) Internet of Things (IoT) applications for various needs such as medication adherence, monitoring, diagnosis, dosage metering and others [6], as shown in Fig. 3.

3) Robotics in applications including companionship, assisted-living, exoskeletons and other rehabilitation applications [7].

4) Smartphone Applications that monitor both healthy members and patients who have acute or chronic needs [8].

5) Immersive Technology applications such as Virtual Reality (VR), Augment Reality (AR), Hybrid or Mixed Reality (MR) for home healthcare [9].

6) Machine Learning and related artificial intelligence techniques for assisting at-home healthcare [10].

7) Innovative form factors such as portable devices, wearables [11], and smart clothes [12] allow for the development of customized, personal home healthcare solutions.

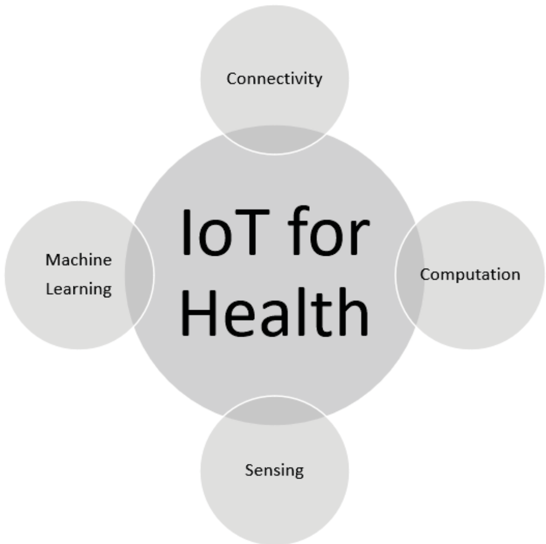

Fig. 3. IoT solution framework for healthcare applications

Different technological paradigms will be required to serve disparate home healthcare situations and needs. In many conditions, technologies will have to be combined to offer optimal care. This can include technologies that allow for monitoring, diagnosis, therapy and Electronic Health Record (EHR) to be integrated and customized to serve patient needs.

B. Factors affecting Technology in Healthcare Applications

There are several factors that govern the selection of technologies for the applications:

1) Patient Needs: Patients may have limitations that require multiple technologies to be combined and applied to serve their unique needs. The limitations may include physical limitations such as with those have physical disabilities. In certain chronic conditions such as diabetes, patients may suffer from reduce visual acuity, which necessitates the creation of special visual aids or auditory means of communication.

2) Communication Availability: Many applications such as telemedicine and smartphone applications among others will require internet networks and/or mobile network connectivity for successful deployment. Newer communication modes such as Long Range Wide Area Network (LoRAWAN) and Zigbee may help fill some of the gaps in communication network availability [13], [14].

3) On-Site Intelligence: Classical artificial intelligence applications perform intelligence on the cloud and translate learnings into recommendations and insights. However, certain healthcare applications may not tolerate latency between data collection and the production of actionable intelligence for the patients. In such cases, on-site or on-device artificial intelligence can review data using machine learning algorithms, and provide immediate actionable insights, also termed edge computing [15]. Edge computing is also suitable for applications where power consumption and related factors are a concern.

4) Cost Optimization: Healthcare solutions, especially those requiring customization must be optimized for implementation and operational costs to reach a wider arc of patients requiring in-home healthcare solutions. Solutions such as telemedicine naturally reduce the cost of home healthcare [16]. However it is important that all solutions be as optimized for cost as possible, by design.

5) Interoperability: Widely divergent solutions can lead to implementation or operational failures in healthcare solutions. Healthcare solutions must use frameworks that are either entirely open, or allow for integration with other solution frameworks, such as Electronic Health Records (EHRs) and other instruments, so that patients and caregivers can integrate multiple solutions [17]. Interoperability standards are proposed that willw ork in specific regions

C. Personalization and DIY Home Healthcare solutions

An area of growing interest in home healthcare includes the development of personalized solutions that patients or their caregivers can design and implement themselves, termed Do-It-Yourself (DIY) care [18], [19]. For successful implementation and operation, DIY solutions must have the following characteristics:

1) The entire solution must be open including hardware, software. There must be minimum ambiguity in the solution, so that it can either be implemented as-is, or modified as required, for the patient or the caregivers.

2) Software applications must be based on programming languages and frameworks that do not require any fees for use, and the lowest possible total cost of ownership.

3) Where possible, hardware must be assembled with off-the-shelf, standard components. When customization or custom design is required, the customization should be minimal, and designs must be shared. This includes designs for housings, printed circuit boards (PCBs) and other design elements require for the healthcare solution. The authors have experience designing solutions with open software and hardware for various healthcare solutions [20], [21].

4) The solutions must take advantage of modalities such as additive manufacturing, commonly referred to as 3D Printing for the replication of housings, chassis and other mechanical structural components of assemblies. This allows for the reproduction of solutions globally without special processes or other impediments.

5) Additive Manufacturing is especially useful in developing custom prosthetics and satisfying other requirements for assisted living [22].

6) Open Computation Tools such as the Arduino architecture or tools widely adapted for open solutions [23], such as the Raspberry Pi Single Board Computer (SBC) should be used wherever possible [24]. Widely used computational tools with a broad range of experiences allow for the consideration of various risk factors associated with the designs such as performance, power consumption and security risks.

7) In relation to machine learning and edge computing, open software tools such as TensorFlow [25] and TinyML [26] must be selected for solution development.

8) The solutions must be designed to be scalable, mass producible, repairable and maintainable to allow for wide adoption by patients and caregivers everywhere.

9) In the future, specialized additive manufacturing techniques can be used for personalized medicine, such as the piecewise manufacturing of pharmaceutical doses that meet patient needs while minimizing adverse side effects [27].

10) The reproducibility and repeatability of solutions is pivotal to their adoption and success. To support this end, scientific studies must be performed on DIY solutions. This will require appropriate funding, patient and caregiver recruitment and other tools essential to the performance of such studies. Results from the scientific publications will further strengthen DIY solutions and allow for the further development and iteration of solutions.

In this position paper, the authors present perspectives on frugal designs of personalized healthcare solutions derived from Proof-of-Concept (PoC) and prototype open-source solutions developed by the authors.

II. HOME HEALTH APPLICATION EXAMPLES

A. Dashboarding Solutions

A vital area of home healthcare is in healthcare parameter monitoring. Monitoring data presented through dashboards can provide very resourceful to caregivers, patients, and healthy individuals alike. Dashboarding can also be used for patient education at home, and various other settings [28].

Using activity monitor wearables, such as the Fitbit, the authors have designed two generations of dashboards to help active individuals understand their activity level on a given day. Their current step count at any point is visually represented for quick assessment. Both designs are entirely open, based on the Raspberry Pi architecture, are extensible and customizable as well as wearable-agnostic. The prototypes were exhibited at multiple Maker Faires across the United States, and detailed articles were published on the designs.

The first-generation Personal Health Dashboard is shown in Fig. 4. There are 8 LEDs arranged in a row, and as the person walks more throughout the day and accomplishes their step goal, the LEDs light up one after another. The data for each day's step count is obtained through the wearable device's API, and the dashboard is powered by a Raspberry Pi [29], [30].

Based on the authors' own experience and feedback received a second-generation Personal Health Dashboard was designed, displayed in Fig. 5. The second generation can display the actual number of steps left in a day's goal, functioning as a count-down counter, or simply count upwards showing actual daily progress as the number of steps. It also has a much larger footprint, so that the user cannot ignore the dashboard. Physical LEDs were selected and programmed. The computing for the device is driven by the Raspberry Pi Zero, while the LEDs are driven by an Arduino microcontroller [31].

Fig. 4. First-generation Personal Health Dashboard

Fig. 5. Second-generation Personal Health Dashboard

The next generation design of the dashboard, currently underway, includes machine learning elements and auditory messages, which relay step-count, the number of steps left to accomplish the daily goal, and other pertinent messages. An attempt is under-way to use machine learning techniques to design features such that the counter will respond to text or auditory queries. A wearable design with haptic feedback is currently under design. There are plans to incorporate gamification to improve adaptability and adherence to activity requirements or rehabilitation.

The dashboard designs can be used for monitoring other health and activity parameters. It must be noted that dashboards though commonly visual, can also be designed to provide auditory feedback. Similarly, auditory feedback from dashboards can aid those with visual impairment. Further, haptic feedback can aid those with visual and auditory impairments. Dashboarding solutions may also be designed to present multimodal responses for patients who prefer or require multiple modes, as shown in Fig. 6.

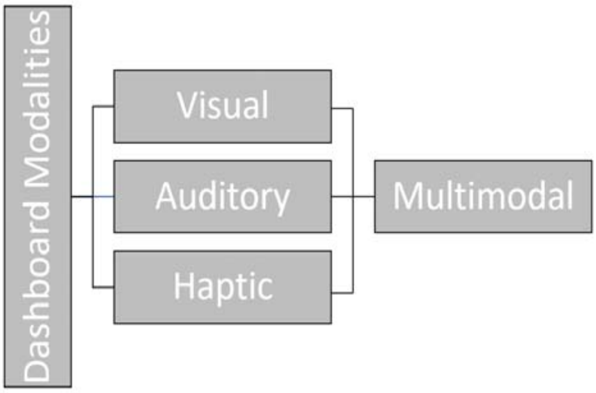

Fig. 6. Dashboard Response Modalities

B. *Thermometry Solutions*

The coronavirus pandemic has required the development of several healthcare solutions. Body temperature measurement is one of the key needs defined for communal health and safety, helping identify and isolate those with potential infections. Both non-contact and contact thermometry methods are required, for different needs and are described in Fig. 7.

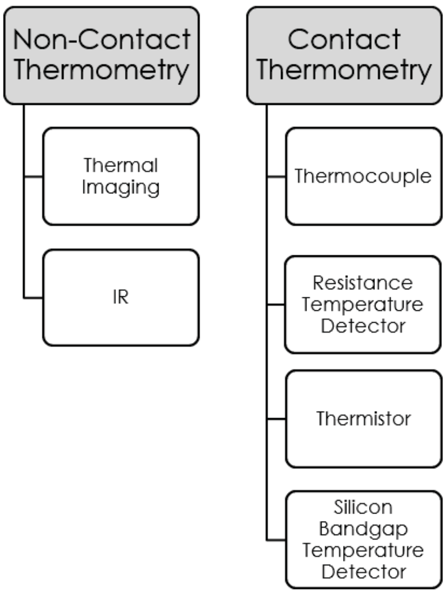

Fig. 7. Body Temperature Measurement Modalities

The team designed one solution for a non-contact thermometer [21] and one for a contact thermometer [32]. Both solutions have uses both during the pandemic, as well as, in other settings. The contact thermometer, for instance can be used by pregnant women, as well as recent mothers who are caring for infants. Similarly, non-contact thermometers are required in various large group settings such as schools, stores, offices, and other establishments.

These two designs are examples of open health solutions that can be reproduced and adapted by anyone during the pandemic and beyond. They also constitute examples of products that undergo the transition from requirements to concepts and prototypes through remote collaboration, occurring at a rapid pace, with the aid of various technologies, at the disposal of designers, engineers and artists everywhere.

In addition, the team has other designs in progress, including the design of a particulate matter counter, an edge computing capable platform for health application and others.

III. LOW-COST DEVELOPMENT AND SOLUTIONS

Economics plays a multi-faceted role in home-healthcare solutions. The Total Cost of Ownership (TCO) comprises of the following critical components:

1) Development Costs: Typical development costs, which may be iterative, include:
- *a.* Hardware Costs
- *b.* Software Costs
- *c.* Prototyping Costs

2) Implement Costs: Product Implementation costs include:
- *a.* Product Maturation
- *b.* Design Transfer and Pilot Line Development
- *c.* Manufacturing Scaling
- *d.* Licensing Fees
- *e.* Regulatory Approval and Product Certification

3) Operational Costs [34]:
- *a.* Insurance and Start-Up
- *b.* Equipment, Fixture and Tooling
- *c.* Plant operations, repair and maintenance
- *d.* Inventory costs
- *e.* Plant Service costs
- *f.* Maintenance, Repair and Service of products
- *g.* End of Life Costs

Total Cost of Ownership models for healthcare, especially for assisted living are sparsely available [35]. Therefore, groups and organizations engaged in the design and distribution of healthcare products for various home and assisted must develop custom models tailored to specific products. There are certain factors that affect the various components of the TCO.

A. *Factors affecting Total Cost of Ownership*

The following are key factors that affect TCO for home healthcare solutions:

1) The regions in which the product and/or solution will be implemented.

2) The demographics of those being served, and their ability to defray expenses [36].

3) The availability and cost of technological solutions such as internet connectivity and other aspects fundamental to the successful function of the product [37].

4) Local healthcare and related regulations that affect care and solution delivery [38].

5) The level of trust patients and their caregivers place on healthcare products, services and their vendors [39].

The cost components and factors affecting the costs make it difficult to develop generalized models for low-cost, personalized, DIY healthcare products. On a case-by-case basis, the total cost of ownership must be modeled and iterated. The authors' experience has been that low-cost innovative products can range around the $100 USD mark for Proof-of-Concept. Prototype costs can be reduced about 1X, and at scale, up to 5X or greater savings can be accomplished.

IV. Discussion of Position

Home healthcare needs vary per the needs of patients and caregivers, as well, as with the emergence of epidemics and pandemics. Home health solutions are not only aimed at patients with chronic and acute conditions, but also at rehabilitating and healthy individuals to meet various goals. It is important to remember that solutions developed for home healthcare will also benefit caregivers, especially at times such as the pandemic, that places additional stresses on caregivers and their own physical and mental wellbeing [40].

Technology can be applied to the solutions themselves, as well as in the design and manufacturing of the products associated with solutions. The emergence of various paradigms such as telemedicine, IoT, immersive technologies, machine learning and others facilitate the development of solutions that can be personalized to patient needs, while optimizing for a range of parameters from performance to cost.

Our position, as laid out through the examples of our own experience is that the best approach to promote the rapid development of innovative healthcare solutions is by encouraging entirely open, standard designs. Technological innovations should be applied as soon as feasible to provide ample opportunities for testing prototypes and iterating designs.

Open designs that align with standards allow for interoperability between solutions. Home healthcare applications may not be standalone. They may have to interact with other paradigms such as smart homes. This would require interoperability in terms of network communications, data interchangeability as well as hardware compatibility such as connection ports and monitors [41], [42], [43].

The scientific, engineering, and clinical communities can provide further impetus by conducting trials and experiments based on the designs and providing feedback on them through publications of results and comparisons.

The participation of global teams in such efforts, can rapidly change how healthcare solutions are designed, personalized, and executed. The coronavirus pandemic has demonstrated and necessitated remote collaboration, and technological innovations will be applicable for the design of products and services by disparate national or international teams.

A final dimension is the cross-pollination of ideas across application areas. Home healthcare products and services can inspire solutions in other areas, such as in smart homes and smart cities. Similarly, applications in other areas, such as military and space can be used to implement and improve home healthcare applications for chronic disease management, rehabilitation, and health management. Frugality can also be obtained by scaling products and portions of products by designing them to be applied across multiple areas, thus allowing for large volume of production and derive consequential financial benefits.

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