Technology-Enabled Medication Adherence for Seniors Living in the Community: Experiences, Lessons, and The Road Ahead

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Abstract. Medication non-adherence in seniors can lead to severe health complications, including morbidity, mortality and decreased quality of life. In view of ageing populations worldwide, there is significant interest among the healthcare sector and researchers to improve medication adherence rates for seniors. However, existing studies in the literature focus primarily on identifying the predictors of medication non-adherence. In this paper, we present our work on technology-enabled medication adherence for 24 community-dwelling seniors over a period of more than 2 years. We leverage Internet of Things (IoT) devices to track inferred medication consumption in the seniors' homes, and provide quasi real-time alerts to community caregivers, who can then intervene in a timely manner. Our study suggests that seniors generally do not consume medication on a regular basis (in both the frequency and time domains). However, technology-based approaches that allow for real-time tracking and appropriate interventions by caregivers can be effective in improving the medication adherence of these seniors.

Keywords: medication adherence, seniors, community, technology, IoT

1 Introduction

The number of seniors in Singapore is expected to double between 2015 and 2030; in fact, 2018 marks the year that the number of below-15 year olds will equal that of above-65 year olds [23]. This upward ageing trend is experienced not only in Singapore, but in many other countries worldwide. In tandem with the ageing population, there is an inevitable increase in the demand and expenditure on healthcare services [22]. There is thus a global effort to leverage technology to tackle the ageing population, and enable seniors to *age-in-place* [9] safely and independently, in the comfort and familiarity of their communities.

Older adults typically suffer from multiple chronic illnesses, such as diabetes mellitus, hypertension, high cholesterol, arthritis, cardiovascular diseases and cancer. These seniors partake in *polypharmacy*, which is a term used to refer to the intake of multiple medications on a daily basis. This can potentially increase the risk of medication non-adherence [20]. According to the World Health Organization (WHO), medication adherence is defined to be the 'extent to which a persons behavior corresponds to agreed recommendations from a healthcare provider' [3]. The lack of medication adherence among older persons, in particular, can lead to varying degrees of health complications - including depression, morbidity, mortality, and overall decreased quality of life. This can also lead to an increase in public healthcare spending and further burden public health systems. There is thus substantial interest by both public healthcare groups and the research community to improve medication adherence rates in seniors.

The issue of medication non-adherence among seniors is complex, as there are multi-facted reasons as to why seniors may not adhere to their recommended medication regimes [8]. These reasons may vary across seniors of different education levels, cultures, and age demographics; they are also highly dependent on the seniors' beliefs in medication. Existing studies in the literature focus primarily on medication adherence measures, measuring medication adherence rates in different population cohorts, and identifying predictors of medication adherence [10]. Technology-based approaches such as the use of a tablet-based application has also been proposed in [17] to allow seniors to track medications through medication reminders and digitized (manual) recording of medication intake, with limited success. However, these studies do not provide enablers for real-time quantifiable monitoring of medication adherence, and timely interventions for seniors who are living in the community.

In this paper, we present our experiences and lessons learned from technology-enabled medication adherence for 24 community-dwelling seniors over a period of more than 2 years, with interventions by community caregivers. We make use of Internet of Things (IoT) technology to monitor the inferred medication consumption (and thus non-adherence) of seniors, through the use of sensorized medication boxes. The system captures the timings and frequencies that the seniors use the boxes. Our monitoring system is configured such that alerts are transmitted to community caregivers via an Over-the-Top (OTT) messaging platform, whenever seniors miss their medication (as inferred through non-usage of the sensorized medication box). The rule engine to generate an alert for missed medication intake is defined by a personalized and configurable threshold.

Although there are existing technologically-advanced medication boxes in the market, they (i) are costly; (ii) mainly serve as medication reminders and do not track medication consumption for further analysis; (iii) require seniors to change their existing medication packing and consumption behaviors; (iv) have complex form factors that are unappealing to seniors; and/or (v) are not linked to the caregivers to enable timely interventions to take place. Our study suggests that seniors generally do not consume medication on a regular basis (in both the frequency and time domains). However, technology-based approaches that allow for real-time tracking and appropriate interventions by caregivers can be effective in improving the medication adherence rates of these seniors.

Section 2 discusses related work in the literature. We introduce the system and methodology in Section 3, and present our findings in Section 4. We provide discussions and conclude our work in Sections 5 and 6 respectively.

2 Related Work

Existing work in the literature focus primarily on the following: (i) medication adherence measures; (ii) measuring medication adherence rates in different population cohorts; and/or (iii) identifying predictors of medication adherence.

Medication Adherence Measures Lam and Fresco [16] provides a comprehensive overview of the categories and types of medication adherence measures in the literature. These include: (i) direct measures; (ii) secondary database analysis; (iii) electronic medication packaging devices; (iv) pill counts; and (v) clinical assessments and self-reports. Questionnaries that touch on the issue of medication adherence include the Morisky Medication Adherence Scale (MMAS) [5], Medication Adherence Questionnaire (MAQ) [7] and Brief Medication Questionnaire [2]. They are commonly used to measure medication adherence [12] and/or to identify barriers to adherence. These scales are low-cost, well-validated and easy to administer; however, they have relatively poor sensitivity and specificity, can often be subjective, and may elicit only socially acceptable responses [16]. Electronic medication packaging devices [13] in the form of Medication Events Monitoring Systems (MEMS) can objectively record the date and time that the senior is inferred to have consumed medication, and are known to be highly accurate [16][19]. However, many of these implementations and studies [6] do not include caregiver interventions in the system design and evaluation. Pill counts have also been used to measure medication adherence. However, based on a study by Vik et al [4], pill counts are neither feasible nor accurate in the assessment of medication adherence of more than 30% of community-dwelling seniors, as medication dispense dates often differ from actual medication start dates. In addition, the authors find that the Morisky scale has low reliability, and has poor agreement with the pill count measure.

Medication Adherence Rates There are several studies that look at the medication adherence rates of various demographics and disease profiles, using one or more medication adherence measures. A common finding in these studies [6][12][11] is that the medication adherence rates of the population are low, which can be detrimental to their health - especially for seniors and those with several chronic illnesses.

Identifying Predictors of Medication Adherence Studies that identify predictors of medication adherence allow clinicians and other healthcare professionals to provide interventions and recommendations that can help to improve adherence rates. In [15], complex medication regimes (comprising multiple medication types and multiple daily dosage frequencies) are found to be significant predictors of the number of hospital re-admissions; simplified medication regimes are thus suggested to facilitate better medication adherence and reduce costly re-admissions. Through a cross-sectional questionnaire, [14] asserts that more benign perceptions of illness and greater perceived illness burden can lead to lower medication adherence.

Our study focuses on leveraging IoT technology to improve medication adherence for seniors who are living in the community. While similar IoT sensing technologies have been used to enable ageing-in-place in community-dwelling seniors, they focus primarily on the physical safety and social aspects of the seniors. In this work, we provide an end-to-end system that enables real-time quantifiable monitoring of medication adherence, as well as timely interventions by caregivers, for community-dwelling seniors and their community caregivers.

3 System and Methodology

3.1 Overview

This study on technology-enabled medication adherence for seniors living in the community is conducted as part of an ongoing research project based in Singapore, entitled SHINESeniors (Smart Homes and Intelligent Neighbors to Enable Seniors) [24]. It investigates the potential use of unobtrusive technologies to enable seniors to age-in-place. In SHINESeniors, up to 100 residential homes are instrumented with multi-modal sensors, such as Passive Infra-Red (PIR) motion sensors, door contact sensors, beacons and panic buttons. Data from these sensors are first aggregated by gateways, before being transmitted to backend servers for further processing and analysis. Together with surveys that are administered to the seniors on a regular basis, the project aims to investigate how technology can be used to meet the physical safety, emotional and mental needs of these community-dwelling seniors.

A subset of seniors in SHINESeniors are selected to have additional senorized medication boxes to store their daily medications. Each medication box is instrumented with a door contact sensor (based on reed switch technology), which can detect the timing that the box is used (i.e., opened and closed). The usage of the box is used to infer the medication consumption patterns of the senior; medication non-adherence is thus inferred through non-usage of the sensorized medication box.

The seniors are being cared for by at least one group of community caregivers. Application alert rules are configured such that alerts are delivered to the community caregivers via an OTT messaging platform, whenever a senior misses his/her medication for a personalized and pre-configurable number of days. The community caregivers may proceed to provide care and intervention to the senior, upon receiving the alert. They may also update their observations and intervention plans via the OTT messaging platform; such information is stored at the backend for further processing.

3.2 Study Design

There are two phases of the medication study: (i) **observational**, whereby the inferred medication consumption patterns of the seniors are captured from the sensorized medication box, and no intervention takes place; and (ii) **interventional**, whereby community caregivers receive alerts when the seniors miss their medications. Table 1 summarizes the differences between these two phases of the study.

	Phase I	Phase II
Study type	Observational	Interventional
Senior profile	Generally healthy & socially active	Vulnerable and frequently admitted to hospital
Number of participants	10	14
Ages of participants	69 to 81	60 to 90
Medication types	4 to 10	1 to 15
Medication intake frequency	1 to 3	1 to 4
Number of seniors with sensor monitoring system	10	4

Table 1. Differences between Phase I and Phase II of medication adherence study.

Phase I - Observational Study (Jul 2015 - Jun 2016) A total of 10 participants from the SHINESeniors project are recruited for the medication adherence study. The seniors are selected based on their willingness to participate in the medication adherence study. All of these seniors have their residential homes instrumented with the sensor monitoring system, comprising motion sensors, a door contact sensor and a panic button. The ages of these 10 seniors range between 69 to 81 years old, and each of them is diagnosed between 3 to 8 chronic illnesses (such as diabetes mellitus, hypertension and high cholesterol). Each of them consumes between 4 to 10 medication types on a daily basis, with daily medication intake frequency ranging from 1 to 3 times.

During this initial phase of the study, no interventions are performed. Instead, the study focuses primarily on the following: (i) user experience of the seniors when using the sensorized medication box; (ii) accuracy of the system in capturing medication intake; and (iii) ability of the system to differentiate between seniors who are adherent and those who are not.

Phase II - Interventional Study I (Jun 2016 - present) Another group of 14 senior participants, aged between 60 to 90 years old, are recruited for Phase II of the study. Only 4 out of these seniors have their homes instrumented with the sensor monitoring system. Each senior consumes between 1 to 15 medication types daily, and have daily medication frequency ranging between 1 to 4 times.

The seniors for Phase II suffer from multiple chronic illnesses, and are frequent admitters to a public hospital. They are taken care of by a community caregiving organization, which provides step-down care (such as residential or community-based healthcare services) following hospital discharge. The alerts that are triggered due to medication non-adherence are delivered to these caregivers, who can then provide timely interventions to the seniors.

3.3 System Design and Evolution

IoT Device Frontend The IoT device frontend comprises: (i) an off-the-shelf plastic box that is retrofitted with a wireless, battery-powered sensor node; and (ii) a gateway that transmits the sensor data to the backend server for further processing. Such a retrofitted design allows the senior to select a medication box that is tailored to his/her preferences, such as the size, color and type of box (e.g., lid-based or drawer-based). These are important considerations, especially for seniors who are used to a particular way of storing their medications.

During the initial periods of the study (Jul 2015 - Jun 2017), the sensorized medication box was an in-house prototype based on reed switch technology, and was equipped with a IEEE 802.15.4 radio for wireless communications to the gateway [19]. This posed several limitations, as follows:

1. Despite having low-power sleep mode enabled to reduce energy consumption, the battery of the sensor node had to be replaced every few months, which led to frequent maintenance visits.
2. The wireless communications technology (based on IEEE 802.15.4) of the sensor node was not inter-operable with the gateway that was used for the sensor monitoring system that was already installed in some of the homes of the seniors. Hence, these seniors had to have two gateways installed in their homes - one for the sensor monitoring system, and another for the sensorized medication box.

The IoT device frontend system (of both the sensor monitoring system and sensorized medication box) was upgraded in Jun 2017, to use commercial off-the-shelf sensor devices based on the Z-Wave wireless protocol. The enhanced version of the sensorized medication box is more energy-efficient (thus requiring less frequent battery changes), and is interoperable with the gateway that serves the rest of the sensor monitoring system.

Care and Response Protocol The care and response protocol is designed in close consultation with the community caregivers who are taking care of our senior participants. It takes into consideration the caregivers' operating hours, standard response procedures, as well as service model. Alerts are delivered to the caregivers at a specific time every morning (e.g., 0900 hrs) if any particular senior S_i has missed his/her medication completely for a pre-determined number of consecutive days D_i (as inferred by non-usage of the sensorized medication box). Upon receiving an alert, the caregivers may provide intervention by either calling and/or visiting the senior. Observations and intervention actions are then logged by the responder into the system, through the caregiving messaging platform. Figure 1 summarizes the care and response protocol that is adopted by the community caregivers.

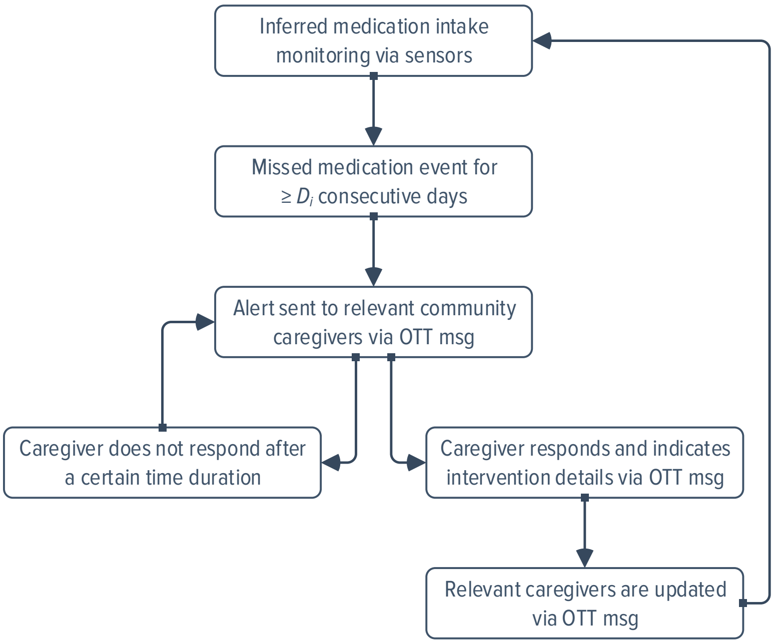


Fig. 1. Care and response protocol for medication non-adherence.

The number of consecutive days D_i of permissible medication misses for a senior S_i before an alert is triggered is dependent on several factors, such as the health conditions and living patterns of the senior, as well as the caregiving workload of the community caregivers. Seniors who require intensive monitoring or require strict medication regimes will be given smaller permissible medication misses before alerts are triggered to their caregivers, as compared to healthier seniors. In addition, the value of D_i for each senior S_i should be configured appropriately such that the total number of alerts that are received by the caregivers are manageable within their workload; otherwise, this may lead to alert fatigue [21] and potentially poorer health outcomes for the seniors.

Caregiving Messaging Platform The caregiving messaging platform enables the delivery of: (i) alerts from the system to the caregivers; and (ii) observations and intervention details from the caregivers to the backend. In the many-to-many caregiving model in our study, multiple community caregivers provide care to many seniors at the same time. As such, one-to-one messaging platforms such as the conventional Short Messaging Service (SMS) are not suitable for use in a collaborative care model setting. Figure 2 illustrates the example whereby SMS was used as the caregiver messaging platform during the initial phase of the study. It was not efficient as the community caregivers had to use a separate group messaging platform to discuss the case before performing interventions.

(a) SMS alerts to caregivers (b) Intervention details from caregivers captured via SMS

Fig. 2. SMS as a caregiving messaging platform. Each message has to broadcasted to all relevant caregivers by sending a SMS message to each caregiver. The names and addresses of the seniors have been removed to preserve anonymity.

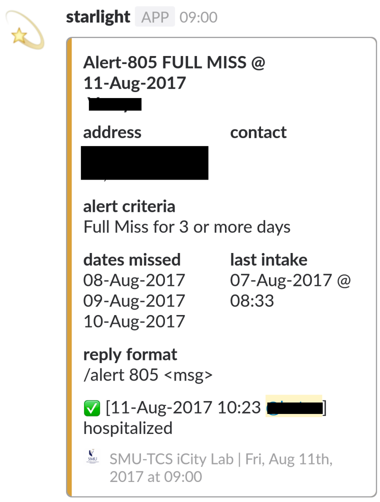
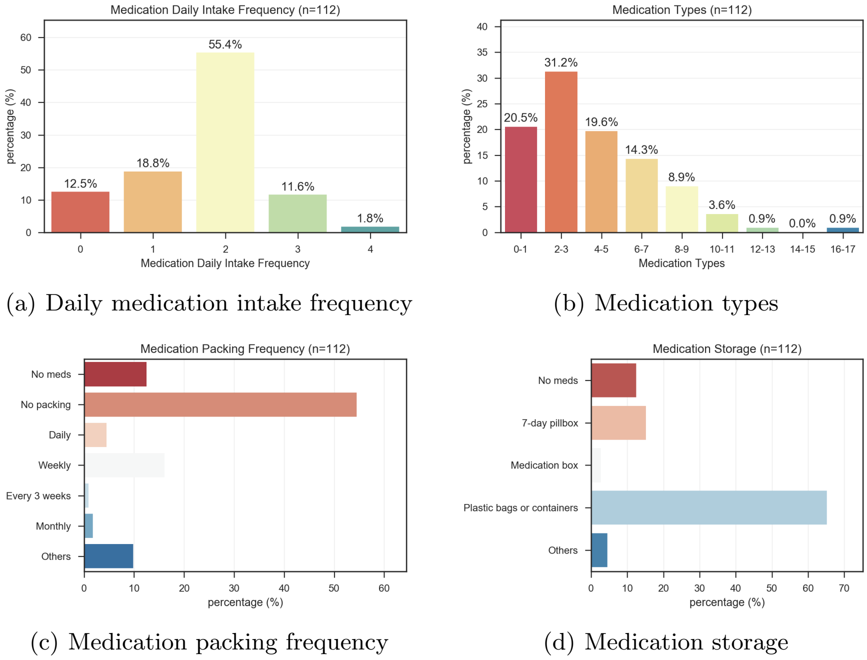


Fig. 3. Slack [26] as a caregiving message platform. Such OTT messaging applications allow for more context delivery during alerts, and enable intervention details to be automatically logged at the backend.



(a) Daily medication intake frequency

(b) Medication types

(c) Medication packing frequency

(d) Medication storage

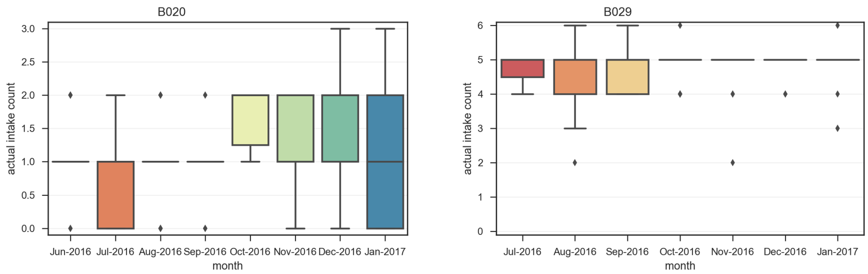
Fig. 4. Medication patterns of the seniors.

In our medication adherence study, we use Slack [26], which is an Over-The-Top (OTT) messaging platform that allows alerts to be delivered to multiple caregivers at the same time, in a group setting. This enables caregivers to collaboratively discuss the senior's case prior to, and after intervention. As seen in Figure 3, interventions that are carried out by the caregivers can also be logged at the backend (via the same messaging platform), for further analysis.

4 Evaluation

4.1 Survey Statistics

A survey was conducted with $n = 112$ seniors in Singapore on their medication behaviors and habits. The ages of the seniors range between 60 to 92 years old, with more than 80% between 70 to 89 years old. 77% and 24% of the seniors are diagnosed with at least 3 and 6 chronic illnesses, respectively. Figure 4 provides a summary of the medication habits of the seniors. Most of the seniors consume medication twice a day, do not pack their medications, and store their medications in plastic bags or containers. 80% of seniors consume at least 2 types of medication on a daily basis. In addition, 80% of seniors do not have packing assistance and 28% of seniors are not aware of the types of medication that they are consuming.



(a) B020 (b) B029

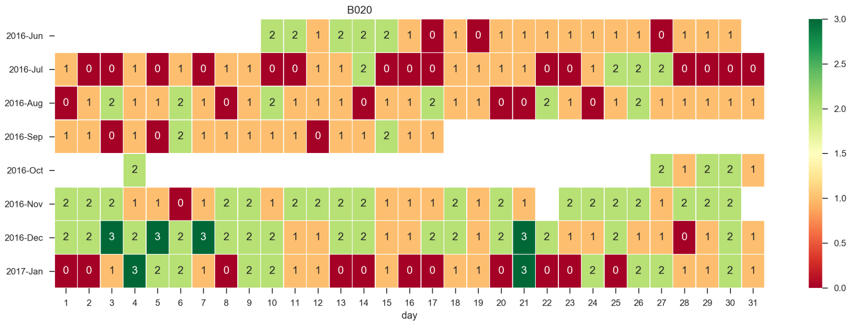
Fig. 5. Boxplots of inferred medication intake frequencies of seniors B020 and B029.

4.2 Sensor Data Analysis

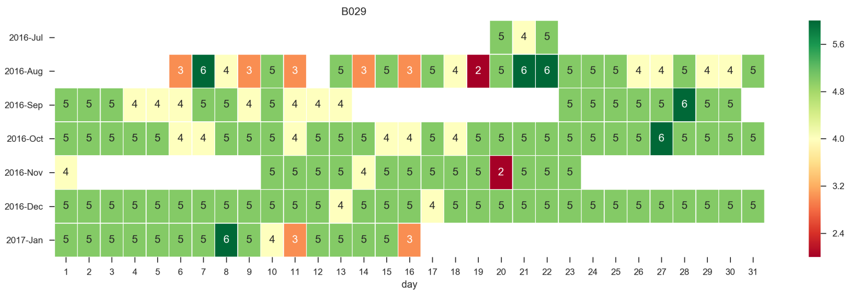
A timestamped data point is generated whenever the senior uses (opens/closes) the sensorized medication box. This allows us to infer the timings and frequencies that seniors consume their medication, on a daily basis. A senior whose sensorized medication box has not triggered any data point for an entire day will be considered as having missed his/her medication for that day. Such real-time monitoring enables community caregivers to identify seniors who are non-adherent to their medication regimes, and to provide prompt interventions to these seniors. Based on the analysis of these sensor data, we are able to generate actionable insights, such as identification of seniors who: (i) are non-adherent to their medication intake (based on inferred timings and/or frequencies); and (ii) have changed their medication consumption patterns over time.

In an earlier paper [19], we use Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [1] to determine the regularity of inferred medication consumption timings. In this section, we focus on the data that is obtained through the inferred daily medication consumption frequency, and highlight two case studies.

Improved Medication Adherence Following Interventions Figure 5(b) illustrates the boxplot of inferred medication intake of senior B029, between Jul 2016 to Jan 2017. The corresponding calendar view of the inferred medication intake is shown in Figure 6(b). During the initial months (Jul - Sep 2016) following installation of the sensorized medication box, it was found that the senior was not very adherent to her medication regime. Community caregivers were notified, and subsequently intervened. The community caregivers found that: (i) the senior had a complex medication regime of 5 times a day; and (ii) medication was being administered by the senior's daughter, who was sometimes confused about the medication regime. In Sep 2016, the community caregivers spent time to educate the daughter on the exact timings that medication should be administered to the senior, and to perform medication reconciliation. Following the



(a) B020



(b) B029

Fig. 6. Inferred daily medication intake frequencies of seniors B020 and B029. Days with full medication misses are shaded in red. Days with missing data are shaded in white.

intervention, the medication adherence of the senior improved, as can be seen from the figures.

Detection of Deteriorating Health The inferred medication intake frequency of senior B020 is shown in Figures 5(a) and 6(a). Her medication consumption patterns changed between Oct 2016 to Jan 2017, shortly before she passed away due to poor health in Feb 2017. As alerts are triggered to the community caregivers only when there are three consecutive days of full medication dosage misses, the caregivers were not notified of the changes in her medication consumption in the months before her death. However, through the application of online time-series change-point detection algorithms, such deteriorating health conditions can be picked up in a more timely manner in the future, so that early intervention can possibly take place.

5 Discussion

Medication Adherence Monitoring for Varying Senior Demographics There are several design considerations that are tailored to suit the specific needs and preferences of the seniors in our study. The sensorized medication box is deliberately kept simple, and can be retrofitted onto off-the-shelf boxes of any size; this lowers the barrier of adoption by our seniors, who are of an older demographic and thus more resistant to changes in their medication storage habits. Prior to this study, we observed that majority of them store their medications in plastic bags of varying sizes, which could contain up to months' worth of various prescription medicine.

In prior art, missed medication reminders are sent to the seniors directly - for instance, via Short Message Service (SMS). However, in our study, such alerts/reminders are delivered to the caregivers instead, as many of our seniors are illiterate and/or do not have mobile phones.

Ecosystem for Medication Adherence Medication adherence in seniors is a salient issue that plagues healthcare providers worldwide. However, the means to achieve this in a viable and sustainable way requires integration of various components in the healthcare ecosystem. For instance, there is a need to engage pharmacy and dispensing systems much more deeply, so as to create direct integration points beyond typical over-the-counter processes seen today. This will allow the entire medication process to be streamlined.

For example, medicine can be dispensed directly into sensorized medication boxes, for monitoring by the caregivers and other care professionals (such as nurses, doctors and pharmacists). In addition, this also opens up market potential for new services, such as automated dispensing and home delivery when medicine supply is detected to be running low. This could be significantly more convenient for seniors - especially those who are non-ambulant. However, we recognize that this is subject to the myriad of the systems and laws governing the dispensation of medicine in different countries. Furthermore, a more tightly-integrated ecosystem will allow healthcare records of seniors to be consolidated, so that healthcare professionals can more objectively and quantitatively evaluate the effectiveness of their medication regimes.

6 Conclusion

In this paper, we document our experiences and lessons learned through the design, implementation and test-bedding of technology-enabled medication adherence for 24 seniors who are living in the community. By leveraging IoT devices, we can quantitatively monitor the timings and frequencies of the inferred medication consumption patterns of seniors, and trigger alerts to community caregivers via a messaging platform. Intervention details are then logged through the same messaging platform, for further qualitative analysis.

The various sub-components of our system design has undergone several iterations, over the study duration of 2 years, and will continue to evolve with changing stakeholder requirements as well as technological advancements. Based on our evaluation, such a system provides evidence-based adherence monitoring, as opposed to prior work that relies on self-reported adherence. We find that technology-enabled monitoring can be effective for both the seniors and caregivers, only if: (i) seniors do not have to drastically modify their existing medication consumption habits; (ii) caregivers are able to intervene in a timely manner, through the delivery of real-time alerts; and (iii) alerts for each senior can be personalized, based on his/her unique profile and health condition.

In the near future, we envision that such medication adherence monitoring (and interventions) can be more tightly-integrated with the rest of the healthcare ecosystem, comprising the senior's longitudinal health profile - such as information on hospital admissions, medication discharge list and biomarkers. This will enable healthcare professionals to provide better care for the increasingly-aging population, and for seniors themselves to enjoy better qualities of life.

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