Data for Healthy Decisions: Computation for Passive Monitoring of Medium-Risk Individuals at Home

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***Abstract*— Many senior adults living independently are at some risk of severe health problems, and have adult caregivers who do not live with them. There is a need for positive indicators of well being to be available to those caregivers. Technology that requires the senior adult to actively perform tasks, such as filling out logs or hooking up sensors, may not be effective, due to the burden on the individual leading to non-compliance. What is needed is technology that is largely passive, installed unobtrusively in the home, that can generate the data needed for calculating indicators of well being. Such data is useful to remote caregivers as well as to medical professionals. One example of such a system, a prototype used to passively monitor and compute nocturnal trips to the bathroom, is presented. Data were collected from 7 senior adults living alone over a four-week period. Computational challenges were significant. Effectiveness of such technology requires social acceptance, ease of use, data security, and calculation of reliable, actionable metrics.**

Keywords- Computational social science; social analytics, independent living.

I. Introduction

Increasing life expectancy across the developed and developing world results in significant increases in the sheer number of senior adults, and in many countries, of the percentage of the population that are seniors. The quality of life experienced by seniors is directly impacted by the adequacy and efficacy of the health care they receive. There are tradeoffs between the common desire for seniors to continue to live independently, versus the need to monitor and manage risk factors related to health.

Senior adults tend to value their ability to continue to live independently, either in their long-occupied home, or in a newer domicile. Independent living is a strong contributor to Subject Well Being (SWB) in senior adults, and higher levels of SWB are associated with better health outcomes [1].

Individuals who live alone – even if in a close community – may be at particular risk for maladies that are associated with general trends of decline. Poor sleep, poor medication adherence, and poor nutrition are examples of trends that are associated with increased risk of a multitude of health problems that may require treatment. The problem is likely worse when living conditions are more isolated.

Many senior adults continue to live quite active lifestyles, especially in the earlier years of that period labeled as “elderly”. These individuals may be considered low risk. Some develop acute conditions that require close medical monitoring for a period of time, while others develop chronic illnesses or other chronic conditions that require medical monitoring on a continuing basis. These individuals may be considered high risk. For such individuals, whether on temporary or long-term basis, it is reasonable to expect that the devices and procedures used for medical monitoring may be somewhat intrusive, and may require active participation by the individual being monitored.

In the present paper, a third group of senior adults is of primary interest. These are perhaps well described as “medium risk”, in that they have no particular health issues that require ongoing monitoring, but are experiencing some general trends that are predictive of increasing probabilities of various health problems. An increased risk of falling is an obvious concern, especially for people who live alone. Undetected rapid growth of certain skin features, such as moles or warts, is another. This list of examples can go on and on; the challenge is to find ways to help monitor general indicators in a way that can help the individual, and care givers (e.g., an adult child), make good decisions about (a) medical interventions that may be needed, and (b) whether continued independent living is wise.

One example of a general indicator of risk is gait speed. Imagine two senior adults walking in the park. One may walk confidently, at a pace unchanged since middle age. The second may walk hesitantly, with a much slower pace and somewhat irregular gait. This second person not only has a higher risk of falling, but also has a higher risk of cognitive decline, disability, and other maladies [2]. Thus, monitoring gait speed could help with a general assessment of a person’s level of risk.

A second general trend, and the one of particular interest in the present paper, is the number of nocturnal (nighttime) trips to the bathroom to void the bladder. Falls are but one risk during nocturnal trips to the bathroom. Frequent nighttime urination, known as nocturia, is common in older adults. Up to three fifths of the senior adult population void at least twice during the night [3]. In this context, a nocturnal void means the person awakes from sleep, goes to the bathroom and voids the bladder, and returns to bed and to sleep. In addition to a potential fall, these frequent trips directly reduce sleep quality, which in turn is a general

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predictor of increased risk. Perhaps more importantly, nocturia can also be an indicator of other serious health conditions (including chronic kidney disease and congestive heart failure), and may indicate a general neurological decline in which the brain's ability to control the kidneys at night (to produce more concentrated urine) is lessening.

In Section 2 below, an example of a passive monitoring system focused on monitoring indicators of nocturia is presented. The example system is a prototype kit of sensors used in an exploratory study [4], aimed at identifying key challenges for this type of monitoring. Results from that study are summarized in Section 3. Discussion of the technical challenges, ease of use issues, and computational methods appears in Section 4. In Section 5, the key attributes of a passive monitoring system that would achieve the goals of unobtrusively monitoring medium-risk individuals at home are described.

II. EXAMPLE

The kit used in the exploratory study featured Commercial Off The Shelf (COTS), prototype, and custom components, specifically chosen to unobtrusively measure indicators of nocturnal trips to the toilet. The kit was placed in the homes of eight research participants for a period of four weeks. The data were used to develop the computational algorithms necessary to automatically compute the number of trips to the bathroom each night, and to compile that data by individual in a summary form suitable to share with a caregiver.

The kit consisted of the following components:

- A COTS sleep tracker called Beddit, which is installed under the sheet and measures bed presence along with various physiological parameters used to infer sleep state.
- A prototype sensor called SmartMat, which primarily consists of a pressure sensitive film affixed to the underside of a mat. We placed the mat in front of the toilet in the homes of the participants.
- The Misfit Shine, a COTS activity tracker worn on the wrist that detects steps and sleep, among other things.
- A custom built proximity detector that we dubbed the Ping Presence Sensor (PPS), which used ultrasound to detect a person sitting on, or standing in front of, the toilet.

These components permitted redundant measures of sleep and proximity to the toilet, and single measures of steps and bed presence. With ideal data, it should have been possible to parse for the following sequence: bed presence, sleep, bed departure, steps, toilet proximity, steps, bed presence, and sleep. The number of times this sequence occurred each night was the measurement of interest in the study.

III. RESULTS

Given that the components used in this kit were a mixture of COTS, prototype, and custom components, it was not surprising that there were numerous instances of lost or corrupted data. The Beddit bed presence sensor generally worked well, but did not reliably sense bed presence or sleep state when the participant was in a position that was partially off the sensor. This was a bigger problem with participants who slept in a queen sized bed. The SmartMat exhibited a data loss problem when it temporarily lost data connectivity – a problem not seen in preliminary pilot testing – and required a power cycle to resume proper data collection. The PPS was dependent on a direct line of sight between the sensor and the person seated on (or standing in front of) the toilet. There were instances of the other objects also being placed on the back of the toilet, partially blocking the direct line of sight, and hence corrupting the data from this sensor.

A different set of challenges emerged with the Misfit Shine activity tracker. The data were reliably collected and stored on the device, but the device did not reliably synch with the IPod that was paired with it. The path to get the data off the device required the IPod to retrieve the data and then upload it to a cloud-based service. The research technicians were able to manually trigger the synch operation during the last home visit; little data were lost. Nevertheless. these data were not available for use in computing day-to-day results as the study progressed. Another issue was that the default data provided by the device was simply a summary of the total number of steps for a day (midnight to midnight). Time-stamped step data would have been better, for use in algorithms to help distinguish the cases of interest (simple trips to the toilet) from other cases in which the person left the bed and performed some other action (e.g., going to the kitchen), as well as going to the toilet. Rectifying this problem would have required interaction with the engineers for the device and access to a special device configuration not normally used with consumers. Consequently, it was not possible to use the time-stamped step data in our algorithms.

Usable data sets were obtained from seven of the eight participants. The kit placed in the home of the eighth participant repeatedly malfunctioned, and the participant had difficulty performing the required tasks. A set of algorithms were developed to align the data from the four sources, and to identify patterns that fit the profile of interest. For each of the seven participants, there were a few nights that had data amenable to straightforward parsing. More generally, though, the data for a given participant on a given night tended to have data missing or corrupted from at least one of the four components of the kit.

A general observation on the computing challenges is that the two COTS products provided data that were easier to integrate, whereas the prototype and custom components provided data that were more challenging. The COTS product data had reliable time stamps, but required some post-processing to combine data from two days (midnight to midnight) into a single night. The data from the prototype and custom components were also time-stamped, but there appeared to be some drift or inaccuracy in the time base, as there were many instances in which the time stamp of the toilet proximity event differed between the two components, and in some cases, was logged as earlier than the bed exit event.

The pervasive challenge was that the incomplete data did not provide a solid basis for computing reliable counts of the number of trips to the toilet during the night. In some instances, it was possible to manually inspect the data and spot an anomaly that, if corrected, could result in apparently correct data. Thus it is possible to include case-by-case anomaly corrections into the algorithms, but this required manual detection (and understanding) of the anomaly.

IV. DISCUSSION

This section contains a description of the research results related to technical feasibility of the technology, ease of use by the participants, and the computing challenges that were encountered during the execution of the study.

A. Technical Feasibility

The example described above demonstrates that it is technically feasible to collect certain data of interest for medium risk individuals in a home setting, without imposing undue burdens on the person to perform required tasks, such as starting or stopping a device, manually transferring data, or keeping logs. A combination of consumer products (especially from the burgeoning personal fitness sector) and custom-designed components can yield a combined data set that supports calculation of the measures of interest.

Although feasible, there are significant technical challenges ahead. Power management, especially for devices powered by batteries, will be a challenge. In the example study, the Beddit sensor was powered through an electrical plug, and the other three devices ran off batteries. The Misfit Shine required regular recharging (preferably daily.) The SmartMat and the PPS had batteries that were sufficient for the four-week study, but would have required replacement for a longer deployment period.

The network connectivity of the devices was also a technical challenge. The Beddit and the Misfit Shine relied on transferring data through a mobile device (tablet or phone) to a cloud-based service, and thus required an internet connection that could be accessed by the device. The SmartMat also required its own data connection through WiFi, and did not automatically reconnect in certain conditions after interruption.

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B. Ease of Use

The two commercial products required some minimal interaction from the participants, but were generally typical of products in the commercial fitness tracking market. Usability concerns will be greater when using such products with some senior adults – those less familiar with mobile devices in general, and with common actions, such as pairing and synching.

The other two components were generally easy to use and required little active cooperation from the research participants. Their effectiveness, though, required the participant to leave them in place and to leave them configured as intended. In a longer term deployment, laundering the SmartMat would be an issue. Neither of these two components provided any direct signal to the participant if they had malfunctioned or were not configured correctly.

C. Computing Challenges

The computing challenges were significant. If commercial products are to be used, it is desirable to get their data in relatively raw form (e.g., time stamped step data rather than daily summaries). Summary data for the midnight-to-midnight day will have limitations on its usefulness to compute the measures of interest. Partial redundancy on certain measures led to higher confidence when both agreed, and allowed computation of a measure of interest when one was absent. Cases in which they disagreed, however, led to anomalies that had to be manually corrected.

The algorithms themselves were relatively straightforward to develop for the subset of data that were intact. Applying a time-stamp correction in the form of an offset solved some data problems, and this process could probably be automated. Many of the other anomalies, however, required manual inspection and speculation to resolve. For example, in one instance the SmartMat showed proximity to the toilet when the PPS did not, and the Beddit indicated the participant was in the bed. The proximity signal persisted for many minutes. We speculated that the participant's pet had probably laid down on the mat for that period of time, and manually discarded it.

In the example study, participant eligibility required that they live alone, normally sleep in the same bed each night, and normally use the same toilet during the night. The computational challenges will increase significantly with more than one occupant, especially if they sleep in the same bed. With more than one occupant, however, there may be less need for passive monitoring.

V. KEY ATTRIBUTES

This section presents a description of the key attributes of systems that will provide the capability to monitor medium-risk individuals in the home, unobtrusively.

A. Ease of Use for the Intended Population

Ideally, the technology used for this type of monitoring should only require consent for the equipment to be installed in the home. Realistically, though, it may require some user actions, such as replacing batteries. Initial actions, such as entering network credentials, could be performed by a technician or another caregiver. Day to day activities, including donning and doffing a device, charging and synching a device, or updating a device, should be as non-intrusive as possible, and should be commensurate with the types of actions already familiar to the individual.

It is important that such technology not be reliant on active participation and cooperation, such as entering data or completing logs. It is also important that normal activities, such as house cleaning, be minimally impacted by the presence of the technology.

B. Data Security and Privacy Protection

Given that the intended use of technology of interest in this research is to promote independent living for senior adults as long as they wish, and that it wise to do so, it is vitally important that the senior adult not feel like the technology is too intrusive on their privacy. It is important that the data be provided, securely, to only those people acceptable to the senior adult. Further, it is essential that the data are positively associated with the senior adult, not inadvertently collected from guests or other non-occupants in the home temporarily (e.g., service providers).

The reliable availability of the data to the caregiver is also important. If the caregiver, living elsewhere, is to use these data to help monitor well being of the senior adult, prolonged periods of unavailable data will be counterproductive. Instances in which the data have become unavailable should be flagged for correction.

C. Actionable Metrics

Most importantly, the technology of interest should provide to the decision maker clear data on specific instances and general trends so that a decision can be made. Primary decisions of interest are (a) whether a specific follow-up, such as a home visit, is needed, (b) whether a medical intervention, such as a doctor's appointment or trip to a clinic is needed, and (c) whether continued independent living is wise. In many cases there is access to graduated levels of care before residency in a skilled nursing facility is warranted. The graduated levels may include daily visits related to medication and meals, assistance with transportation and general community mobility, and taking measurements (such as blood pressure) directly.

Development of suitable metrics will require a focused research program. The example used in the present paper concentrated on integrating measures of sleep and activity, to produce a simple count of the number of trips to the bathroom during the night. Such data from a single night is not the basis for a decision. Data over weeks and months are needed to establish whether the person routinely awakens to void the bladder more than once per night. Long term data is also needed to establish whether the frequency of the nighttime voids is increasing.

In developing these metrics, it is important to develop positive indicators of well being, as well as indicators of potential concerns. That is, it will be useful to caregivers outside the home if they can see results showing that the person being monitored exhibits such attributes as (a) gets plenty of uninterrupted sleep, (b) is taking their medication appropriately, (c) has good nutrition, (d) has a good gait, (e) has a healthy appearance of the face and skin, and (f) has plenty of social interactions. Such measures, along with others that might be added, are predictive that the senior adult is doing well.

D. Positive Socialization

One can imagine two different socialization paths for passive monitoring technology. There is a negative path, in which the technology is seen as invasive of privacy and denigrating to dignity. On the other hand, there is a positive path, in which the technology is seen as supportive, wise, useful as a precaution, and an enabler of independent living.

Positive socialization will not occur in a vacuum. Introduction of technology that measures the activities described in the present paper is easily labeled as "spying" or other pejorative terms. The current trends in fitness and activity tracking may provide a path for positive socialization. These trends include presentation of feedback to the person on a daily basis, along with a summary of recent (and sometimes long-term) trends, comparing the person's data with data from peers, and sharing data among a designated group.

Current trends across healthcare providers and public health services reveal growing interest in using mobile devices (e.g., smartphones) and the Internet of Things (IoT) to help monitor at-risk individuals, groups and regions. For example, monitoring for spread of infectious diseases in areas of concern can possibly be accomplished more efficiently using specialized sensors that scan populated areas for indicators of interest (e.g., high fever), and combine that data with data from other sources, to more quickly detect spread of serious disease [5]. The hybrid crowdsensing paradigm [6], applied to healthcare, may result in greater familiarity with using general surveillance of people in public places, along with specialized sensors intentionally carried by individuals. This greater familiarity may help facilitate easier acceptance of similar technologies deployed in private residences.

Indeed, there is general interest in leveraging the IoT to improve healthcare for senior adults, across the spectrum of early warning systems (enabled by artificial intelligence), assisted living, and mobile health [7]. IoT data obtained from home appliances, utilities, and smart home technologies may enable the types of algorithms of interest in the present paper to be developed and used to monitor individuals at all levels of risk.

Ultimately, positive socialization will require that the senior adult feel more confident as they continue to live independently, as well as increasing the confidence of caregivers who monitor the metrics remotely. If the technology can improve the SWB of the senior adult, perhaps it will also help promote better health and quality of life outcomes for this segment of the population.

VI. Conclusions and Future Work

It is clear from the results that the goal of monitoring individuals at the medium-risk level, unobtrusively, is attainable. The challenges, however, require deliberate design and engineering to ensure that the burden of making this technology work does not fall on the individual to be monitored. Supporting technologies, such as batteries and wireless communications, are improving at an impressive pace. They will be required for the technology of interest to become successful. Future research should focus on improving the reliability and interoperability of the key component technologies, making it easier to integrate multiple sources of information into an unambiguous chronology of events. Future work is also needed on developing complementary sensors that could provide additional, confirmatory sources of information. One example, investigated in the current effort but not included due to lack of maturity, is technology to monitor water usage in the home. Actions such as flushing the toilet may have a unique signature that, in principle, can be monitored by sensors attached to water lines in the home. Monitoring electrical circuit loads can also provide information about activities such as laundry, cooking, and light housework. Use of mobile communications devices can provide information about community mobility and social interconnectedness. Still further information may come from a variety of sources (such as home appliances) associated with the IoT. Collectively, an array of such technologies can be useful in monitoring medium-risk individuals performing a variety of activities of interest. By combining information about bed presence, sleep, walking (including gait speed), using the toilet, using water and electricity in the home, mobility outside the home, and communications patterns, it may be possible to compute indices of well-being across a wide spectrum of activities that are vital to the physical and mental health of senior adults.

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