Monitoring Living Activities of the Elderly Living Alone Using a Lifeline

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Abstract

As the population ages and the number of older people living alone in Japan increases, creating a society in which they can continue to live safely in their home environments became a pressing issue. Currently proposed IT-based monitoring systems have some drawbacks such as bothersome restrictions and psychological burden. Recently, several systems that monitor essential utilities, and that were non-restraining, non-intrusive, and automatic, have been proposed, but few reports have been made on longer-term experiments. Focusing on “tap water,” which is critical to maintain life and changes in living activities, this study conducted a one-year monitoring of the elderly living alone based on their water usage data. The subjects were 8 seniors of 75 and over living alone in a remote area (2 males, 6 females; average age 84.6±4.2; seven in treatment of cardiovascular diseases). The water flow measured in time unit of five minutes was recorded in the cloud server to monitor the elderly’s water usage. The purpose of this study was to monitor the water usage pattern of the elderly living alone and to verify the time unit proper to infer their daily living activities and patterns. Analysis was conducted to see how they use water in different time units (hour, week, month, and season). Analyzing the relations between the living activities to be studied and the time units for data aggregation identified the time units proper to infer daily living activities, indicating that the system could be effective as a tool to monitor independent living of the elderly.

Keywords: Elderly living alone, IT device, lifeline utilities, living activities, time unit

1. Background

Japanese society is expected to further age with its elderly ratio reaching 39.9% in 2060 from 26.7% in 2015.1) Furthermore, the ratio of the one-person household of people over 65 increased significantly to 26.3% in 2015 from 13.1% in 1986.1) In these circumstances, ensuring safety and security of the elderly’s daily living and prevention of their social isolation became pressing issues. In the depopulated areas where there are many elderly persons living alone, declining physical and cognitive functions as they age and the necessity of on-going medical treatment are also growing serious problems.2)

As the society ages nationwide and the number of elderly living alone increases, Gujo City of Gifu Prefecture launched a model project of monitoring such elderly residents. The monitoring project started in September 2014 in the marginal villages whose population of people over 65 exceeds 80%, the project uses consumption data of “tap water,” an essential utility. Eight elderly persons living alone participated in the project with their and their family’s consent.3) In this project, water usage was recorded in the connected cloud server in time unit of five minutes. Usage of tap water as one of daily essentials was measured and recorded to monitor the life of the elderly persons living alone, as well as to ascertain the elderly’s safety. The elderly persons’ activities were monitored in their daily environments in a nonintrusive way.

The reasons for selecting “water usage” as monitoring data are as follows: 1) water is essential to maintain life, 2) water usage can be monitored for almost all households, 3) privacy is not violated, and 4) water usage data allows inferences about living situations. Gas and electricity have also been used as tools to monitor the elderly. However, gas usage can be monitored only in the service area, and electricity might make it more difficult to detect changes in life rhythm because of standby power consumption and automatic adjustment according to room temperature. In addition, a cold mountainous area, such as the target area, presents some special challenges, including usage fluctuations, due to heating during the winter season.

Although various IT-based monitoring systems have been proposed4-6) and some were actually implemented, as of August 2017, there existed no long-term (over a year) experiments that monitored the elderly persons’ living based on water usage.

This study explored basic methods to verify a vast amount of water usage data measured in time unit of five minutes for one year. To find out what approaches will be effective in monitoring daily living, it analyzed the relation between the living activities to be studied and the time units for data aggregation and identified the time units appropriate to infer specific daily living activities.
2. Methods

(1) Study area

Gujo City of Gifu Prefecture is located roughly in the center of Japan, with about 90% of the area covered by mountain forests.

As of April 1, 2015, the population was 44,158, of which 33.1% was over 65, indicating that it is a significantly aging community. In August 2014, the city launched a model community project of monitoring the elderly (hereinafter “model project”) with concerted efforts from the communities, families, local government, relevant institutions, and the university. The study area consisted of Village C (16 households) and Village D (13 households) of Town A’s District B, whose aging ratio was the highest in the city. The population of District B was 318 or 143 households as of the end of March 2012, with its ratio of over 65 population being 63.2%. Table 1 shows the over 65 population, the number of households, and the aging ratio of each village.

Table 1. Overview of the study area

<table>
<thead>
<tr>
<th>Village</th>
<th>Population</th>
<th>Population over 65 (%)</th>
<th>The number of households</th>
<th>Household living alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Village</td>
<td>29</td>
<td>24</td>
<td>82.8</td>
<td>16</td>
</tr>
<tr>
<td>D Village</td>
<td>28</td>
<td>26</td>
<td>92.9</td>
<td>13</td>
</tr>
</tbody>
</table>

(2) Subjects

Among the model project users, eight households (5 in Village C, 3 in Village D) participated in this study with their consent. Most of their family members lived separately and out of the city, and their visit frequency varied from twice a year (Bon season and New Year) to once a week. Table 2 shows the basic characteristics of the subjects. Average age of two males and six females was 84.6±4.2, all of whom were over 75 in the old-old segment of the Japanese nursing care insurance program. Regarding the degree of independence in daily living, six were certified as “self-supporting” and two as “requiring assistance” with a comprehensive regional support center involved. As for health conditions, seven were in treatment of cardiovascular diseases such as high blood pressure and angina pectoris. They were also seeing doctors for orthopedic diseases (limb pain, backache, etc.) and insomnia.

Table 2. Basic characteristics of the subjects

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age</th>
<th>Gender</th>
<th>History of present illness</th>
<th>Village</th>
<th>Long-Term Care Insurance System Care Necessity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 88</td>
<td>Male</td>
<td>① Hypertension</td>
<td>C</td>
<td>Self-reliant</td>
<td></td>
</tr>
<tr>
<td>B 86</td>
<td>Female</td>
<td>① Hypertension</td>
<td>C</td>
<td>Self-reliant</td>
<td></td>
</tr>
<tr>
<td>C 82</td>
<td>Female</td>
<td>① Hypertension</td>
<td>C</td>
<td>Self-reliant</td>
<td></td>
</tr>
<tr>
<td>D 86</td>
<td>Female</td>
<td>① Hypertension</td>
<td>D</td>
<td>Self-reliant</td>
<td></td>
</tr>
<tr>
<td>E 77</td>
<td>Female</td>
<td>① Hypertension</td>
<td>D</td>
<td>Self-reliant</td>
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<tr>
<td>F 88</td>
<td>Female</td>
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<td>D</td>
<td>Self-reliant</td>
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</tr>
<tr>
<td>G 90</td>
<td>Male</td>
<td>① Hypertension</td>
<td>D</td>
<td>Requiring support 1</td>
<td></td>
</tr>
<tr>
<td>H 80</td>
<td>Female</td>
<td>① Hypertension</td>
<td>D</td>
<td>Requiring support 1</td>
<td></td>
</tr>
</tbody>
</table>

(3) Outline of monitoring system using water usage data

The system (“KIZUKI”) was proposed by Tsukushinbo, a local NPO, and designed and developed by QUALICA Inc. and other companies. In this system, a special meter is installed beside the pre-installed flow meter. The meter detects water flow and sends data via a communication terminal into the central cloud server. Water usage data is then transmitted to guardians via the Internet. Water usage is measured in time unit of five minutes, and data is delivered via email to guardians (including family members and relatives in separate houses, neighbors, NPO, municipality officials, and university officials (“monitoring team” collectively)) 1) when a subject starts to use water in the morning, 2) when water is being used for more than 2 hours, and 3) when water is not used for more than 12 hours. Subjects and their relatives determined who will be their monitoring team members and how to set up email delivery.

(4) Verification methods

Individual water usage data accumulated over one year, from September 2014 (model launch) to end of August 2015, was analyzed. First, data measured with the time unit of five minutes was aggregated in time
units of 15 minutes, 30 minutes, one hour and three hours. Next, the relation between the living activities to be studied and the time units for data aggregation was analyzed to identify the time units appropriate to infer specific daily living activities.

In this study, monitoring is defined as follows: “to monitor daily living activities such as eating, excretion, bathing, washing, sleeping, and going out.” These activities are considered to be linked with human health and are therefore useful in detecting signs of deteriorating health conditions at an early stage.

(5) Ethical considerations
The study was conducted with the approval of the Clinical Research Ethical Review Board of Gifu University Graduate School of Medicine. After explaining the study’s purpose and the voluntary nature of the subjects’ participation, consent forms were obtained from the subjects and their relatives.

3. Results

(1) Data collection
During the one-year study period from September 2014 to the end of August 2015, the mean ± standard deviation of the days when water usage data could be obtained was 351.9±8.8 days and the time when data could not be obtained (lost time) was 706.9±146.5 minutes. The days with lost time (lost day) and days of home exit (day of absence) were excluded from analysis data (Table 3).

Mean ± standard deviation of the day of absence was 10.1±1.3 days, and the lost time per episode was 70 minutes on average. Possible causes behind inability to collect data included: 1) failure of telephone line (radio wave) and/or power failure, 2) trouble with a telephone (3G network), 3) failure of KIZUKI, or 4) malfunction at a receiving center. In case of 1), communication will be back on line once circuit trouble or power failure is cleared. In case of device failure as in 2), 3) and 4), the system will not be resumed unless someone repairs it. Since the lost time zone was almost identical and there was no prolonged data loss recognized in this study, it was determined that partial data loss was generally caused by disrupted telephone line or power failure.

Table 3. Days of measurement

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Measurement day (days)</th>
<th>Lost day (days)</th>
<th>Lost time (minutes)</th>
<th>Day of absence (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>353</td>
<td>12</td>
<td>990</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>354</td>
<td>11</td>
<td>690</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>354</td>
<td>11</td>
<td>750</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>355</td>
<td>10</td>
<td>640</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>356</td>
<td>9</td>
<td>740</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>329</td>
<td>11</td>
<td>810</td>
<td>25</td>
</tr>
<tr>
<td>G</td>
<td>356</td>
<td>9</td>
<td>490</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>358</td>
<td>8</td>
<td>545</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 2. One year trend in water usage by Subject per month (September 2014 to August 2015)

Only one person had a day of absence during the study period. Initially, there were no rules made about absence (home exit). The subject had not consumed water for more than 12 hours and email was sent to his/her monitoring team. Confirmation with this subject revealed that he/she was absent for overnight stay. After this, the subjects or their relatives were required to report to their respective monitoring team in case of overnighting.

(2) Analysis of water usage data
a. Seasonal change of water usage (monthly basis)
Figure 2 shows the subject-specific month-to-month comparison of water usage during the study period (mean value) to see seasonal change. Three subjects (E, F and H) showed stable usage patterns throughout the year, while care insurance program users (G, H) showed less than one-fourth of the water usage of F (highest of all).

Figures 3 and 4 show one-month data of daily water usage measured in time unit of five minutes for Subject B whose water usage varied by season (Fig. 3 – December, Fig. 4 – May (highest)). The area where bar graphs overlap shows that the subject used water at a fixed time zone, indicating his/her regular activity pattern. In December, the subject started to use water around seven in the morning, used water intensively during lunch hour (12:00-13:00) and around 17:30 in the evening, and stopped using water at around 22:00.
Water usage till waking up was inferred for excretion. In May, on the other hand, the subject started to use water around 6:00 in the morning, and in addition to using water around 12:30 and from 17:00-19:00 in the evening, he/she used water around 21:00, with no usage recorded after 22:00. The subject used more water after waking up in May than in December, and used water longer in the evening.

b. Living activity patterns inferred on a weekly basis

Figure 5 shows week-to-week comparison of one-year water usage data (mean value) of Subject E who did not show any seasonal change on a monthly basis. This week-to-week comparison was useful in inferring that living activity patterns vary by day of the week (i.e., going out or going to hospital) as well as by the relatives’ visit status.

c. Living activity patterns inferred on a minute/hourly basis

Daily water usage of Subject G was shown in different time units: five minutes (Fig. 6), 15 minutes (Fig. 7), 30 minutes (Fig. 8), 1 hour (Fig. 9), and 3 hours (Fig. 10). Figure 6 shows H’s daily water usage measured in time unit of five minutes. This data was used to infer living activities like getting up/going to bed, starting/finishing daily activity, excretion, washing face, as well as frequency of excretion during daytime.

Figure 7 shows data aggregated in units of 15 minutes. Here, intensive use during morning, lunch hour, and evening indicates preparing a meal and washing up after a meal. Hourly data was useful in inferring bathing, sleeping at night, and other activities. Washing clothes and bathing were inferred from water usage during the time period from 14:00 to 15:00. No water usage after 21:00 suggested time of sleeping, excretion at night, and sleeping condition.

Figure 10 (3 hour units) made it possible to infer the status of going out and sleeping. No water usage after 21:00 indicated time of sleeping.

4. Discussion

Various monitoring systems using essential utilities, such as water, electricity, and gas, to ascertain the safety of seniors living alone have been practically implemented.7 These systems are simple and easy to use, enabling automatic data collection without any sense of restraint or intrusion to the users. In case of water and gas, unlike electricity which has standby power consumption, users have to act, for example, by turning a faucet or lighting the gas. Both are considered effective in ascertaining safety. Since gas is used mainly for cooking, it might not be effective for monitoring the living activity of the elderly with deteriorated physical functions who cannot cook for themselves any more.

Water, however, is what people always use in daily life and a water monitoring system enables the monitoring of individual living patterns and conditions as well as the ascertaining of safety through usage status. The study revealed that a vast amount of data
measured in time unit of five minutes enabled inferring a rhythm of daily life and living activities in a given time unit for data aggregation.

Various monitoring systems have been presented, such as a system to sense positions or door opening/closing by an infrared sensor or GPS for relatives living separately to ascertain the safety of their elderly.\(^8\)\(^ - \)\(^11\)\) Research has also been conducted for the development of monitoring sensors or data analysis with the aim of predicting falling, detecting signs of cognitive function decline, managing health, or early detection of mental and physical depression.\(^12\)\(^ - \)\(^14\)\) Majority of these studies reported their development of sensor devices or monitoring systems and the verification results of such devices.\(^14\)\) Although various IT-based monitoring devices have been developed, few are in general use. Causes behind this slow progress are reportedly cost of device, reluctance and psychological burden when being monitored by a device, and privacy issues.\(^15\)\(^ - \)\(^18\)\) However, it seems that monitoring daily living based on water usage data could be easily and automatically conducted without any sense of restraint and psychological burden to the users, making it a less stressful system.

a. Effectiveness as a device to ascertain safety and monitor daily living

During the one-year monitoring, there were 10 days of absence and an average lost time of 70 minutes per episode. Communication loss was mainly caused by power failure due to lightning, birds and animals, etcetera, and it was verified that data could be securely collected automatically except in such cases.

At present, monitoring with IT-based sensor was conducted based on the collected data, and thus, monitoring itself could be discontinued when data collection is disrupted. However, in case of KIZUKI, the water meter itself could work as a monitor even in case of failed data collection. Even if any device gets broken, a “human” will go into action if email is not delivered to a monitoring team when a subject is supposed to start using water in the morning. That is, an integrated effort of man and machine is critical in monitoring.

b. Usefulness as a tool to monitor daily living

In this study, how the elderly living alone use water in their daily life was visualized. Analyzing water usage in different time units (minute, hour, week, month, and season) enables inferring a rhythm of daily life and living activities, indicating that it could be useful in monitoring the independent life of the elderly.

c. Living activities inferred by different time units

In this study, water flow was measured in time unit of five minutes, and a vast amount of data collected
over one year was used to explore analysis methods. Since there have been no research on time unit appropriate to infer daily living activities and patterns, this study could be useful in dealing with big data in the future. Living activities associated with water usage include excretion, washing of the face, cooking (kitchen work), cleaning, washing clothes, and bathing. Chronological monitoring of daily water usage enabled inferring the time of starting and finishing specific activities, such as waking up, going to bed, excretion, bathing, cooking, washing clothes. A status of no water usage also enabled inferring sleeping or going out.

First, data aggregated in units of five-minutes was appropriate to infer living activities within a relatively short amount of time, such as excretion and washing of the face. Excretion is critical to support life. In this study, the subjects used 5 to 10 liters per excretion, and water flow data enabled inferring the time zone, frequency, and intervals of excretion. When such five-minute data was aggregated on a weekly or monthly basis, certain regularities in their daily life could be identified (waking up, going to bed, eating, etc.).

Time units of 15 or 30 minutes was useful to infer living activities such as cooking and bathing, while that of 1 or 3 hours were appropriate to infer absence (going out or going to hospital) in daytime and sleeping at night (through a status of no water usage).

Analyzing water usage on a weekly basis made it possible to infer day-of-week regularities in living activities and patterns. In this study, two subjects used the nursing care insurance service, while the remaining six subjects lived independently. Although their physical conditions varied, all of them were in a situation where they had to act on their own to do household chores and maintain their life.

A short duration of use enables detailed measurement/estimation of the usage for tooth brushing or even drinking. However, although a longer duration makes it more difficult to identify activities, it should be noted that shortening time unit without careful consideration might lead to an intrusion of privacy. It is, therefore, important to carefully consider what, why, and to what extent water usage should be monitored. This study covered the major living activities that could be monitored through water usage, and in the next step, it may be necessary to focus on certain living activities, depending on health and living conditions of the subjects. Hence, it is important to define a time unit appropriate for monitoring such activities.

By collecting data and making prolonged observation to see frequency and area of going out, hobbies, social involvement, and community interactions, all of which are hard to gain simply from water usage monitoring, any change in habitual behaviors and living patterns could be detected earlier.

d. Effectiveness for livelihood support
The study results suggested that water usage monitoring could be a tool to ascertain safety of the elderly on a daily basis and to detect early any trouble in their daily living. Majority of the system users were living with certain diseases and physical conditions (high blood pressure, angina pectoris, backache, limb pain, etc.). During the one-year monitoring of water usage, there was no sign of life function deterioration or physical or mental depression. Previous studies reported that the data of individual living patterns accumulated over the long term could increase detection accuracy of any irregularity or change. It is important to further accumulate data in this study as well.

In this study, the time of starting to use water in the morning was inferred as time of waking up, and time of stopping using water as time of going to bed. By comparing and studying one-year water usage in different time units (day, week, month, and season), the subjects’ living activities and patterns could be identified objectively. When looking at individual living activities, all other than Subject H woke up or ate breakfast about 30 to 60 minutes later in summer than in winter, but lunchtime and bedtime were relatively stable, indicating that they have certain fixed living patterns. In case of Subject H, his/her time of starting to use water and time zone of water usage was rather irregular, suggesting his/her rhythm of daily life was not fixed. For example, water usage generally required for bathing and his/her actual data did not match. Bathing is assumed to account for the larger ratio of household water usage, and thus it was difficult to identify living activities in his/her case.

As a result of the one-year monitoring, it could be said that their relatively well-regulated life may be associated with their health conditions although certain seasonal changes were recognized with regard to time of waking up going bed.

e. Limitations of this study and future issues
This study first verified the relations between the living activities to be studied with water usage and the time units for data aggregation. However, as in case of Subject H, who showed discrepancy between water usage required for bathing and the actual measurement or used water continuously at midnight, it was difficult to identify living activities. In addition, frequency of eating, washing clothes, and bathing could vary by subject, as well as the time zone and methods. Bathing methods were also considered to vary by season, including frequency (showering, soaking in the bathtub, etc.).

Even if an IT device enables automatic data collection, it is necessary to check and confirm actual living habits and conditions of the subjects to properly interpret data. In addition, social involvement, which could be associated with the elderly’s health conditions, is hard to learn from water usage. Thus, it
is necessary to collect information about frequency and area of going out, hobbies, status of social involvement, and community interactions. It means that detailed interviews about daily living status is critical in monitoring.

Algorithms have been developed to detect irregularities (in-house accidents or other emergencies) from the data collected by infrared sensors or other devices used for monitoring the elderly. Since this study focuses on a cold depopulated mountainous area, we expect that there will be differences in water usage between the elderly in the target area and their counterparts in urban areas. However, no algorithm analysis has duly considered the regionality and distinctive characteristics of the elderly’s living environments. It is, therefore, necessary to propose and verify various judgment algorithms.

Lastly, in this system, the whole amount of water consumed at a household was detected at one place to infer living activities at every area of the subjects’ life. To increase accuracy in identifying living activities, installation of a flow sensor at every possible spot such as kitchen, toilet, and washroom could be considered. In this case, it is important to give full consideration to specific living activities, i.e., to be focused on users’ physical and living conditions, before determining installation spots. The number of installation spots should be minimized to prevent unnecessary monitoring.

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References
ライフラインを活用した独居高齢者の生活行動のモニタリング

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和文要旨

我が国では、高齢化の進展、独居高齢者の増加に伴い高齢者が安心して住み慣れた地域で暮らすことができるように社会の構築が喫緊の課題となっている。IT 機器による高齢者の見守りも提案されているが見守られる側の拘束感や負担感が指摘されている。近年、無拘束、無意識かつ自動的に見守れる方法としてライフラインを活用したシステムが提案されているが、長期間の実施報告は少ない。本研究はライフラインの中でも生命維持に必要不可欠であり生活行動に伴い変化する「水道」に着眼し、水道水の使用状況から過疎地域の 75 歳以上の独居高齢者 8 名（男性 2 名、女性 6 名、平均年齢 84.6±4.2 歳、循環器疾患受療中 7 名）の生活の見守りを 1 年間行った。5 分毎に計測された水道流量をクラウドサーバに記録し、水道使用量から独居高齢者の生活の見守りを行った。本研究の目的は、独居高齢者の水道使用状況を 1 年間モニタリングし、日常生活行動や生活パターンの推察に適切な時間単位を検討することである。独居高齢者が生活の中でどのように水道を使用するかを異なる時間、週、月、四季単位で解析を行った。検討したい行動行動情報と集計時間単位との関係について分析した結果、日常生活行動の推察に適切な時間単位が明らかとなり、独居高齢者の生活の見守りのツールとしての有用性が示唆された。

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