How Should Remote Monitoring Sensor Be Accurate?

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***Abstract*—The goal of this paper is to find an answer that how remote monitoring sensor should be accurate. To achieve the goal, we propose three methods, generalization by three-actor model, design the algorithm of the three-actor and development of RMS simulator. With the three-actor model, we can generalize RMS by interactions among three actors. As the second step, we design the algorithms that how to work the actor in RMS. So we could express how often the elderly become ill. Moreover, using the developed simulator, we could simulate with many patterns of conditions. The result of simulations shows that if the accuracy of the sensor is greater than 0.9990, then the RMS has much more detectionPower.**

***Keywords*—remote monitoring service for elderly, remote monitoring sensor, accuracy, detectionPower**

I. Introduction

Many countries and societyis are faced with an aging society[1]. Hence, Quality of Life (QoL) for elderly people is becoming more important[2]. Based on the social background, elderly people should live true to themselves. Moreover, they have liberty that they feel happy on individual lifestyles. In order to keep their QoL with individual freedoms, their families and caregivers whom we define as consumers need a method to monitor the livelihood of the elderly people. *Remote monitoring service for elderly people (we call it RMS)* is a very effective method to support elderly people with safe. The RMS provides an elderly family some methods to monitor and confirm an elderly people with safety in remote. Concretely speaking, if a system detects the elderly people become anomaly, then the system notify to elderly's family or service provider for an admonition. With the growth of both ubiquitous computing and sensor technology, many societies developed a wide variety of remote monitoring services[3]. First, to implement the RMS, especially the accuracy of the sensor is a very important component. The remote monitoring sensor obtains the state of elderly people, Thus, many companies and researchers have tried to improve the accuracy of the sensor[4],

However, no one explains that how should remote monitoring sensor be accuracy in RMS as far as we know. Because, many companies and research have conducted to improve the remote monitoring sensor by the technology-driven approach. If we could grasp the requirement of sensor accuracy, we would gain some merits from the requirement in many ways. For example, RMS providers can decide the goal of sensor accuracy more easily.

In this paper, we show how should remote monitoring sensor be accuracy. Specifically, we propose a method to simulate the RMS. With the proposed simulator, we can simulate how the RMS could accuracyly detect the elderly state (we call the accuracy of RMS *detectionPower* in the following sections). To realize the simulation, we propose *three-actor model*, with which we can analyze the main three actors in RMS. We define each actor as *subject*, *watcher* and *elderly*. Especially in this paper, we scope the watcher and elderly. Because the two actor has a relationship which one monitors others. Thus, we define the algorithm of elderly and watcher. For example, we thought elderly people's healthy state algorithm which the elderly condition transits normal or ill. We could develop the RMS simulator with the three-actor model and the their algorithms, which simulates the RMS's behavior.

Moreover, we will conduct three types of simulations with the RMS simulator. In the first simulation,

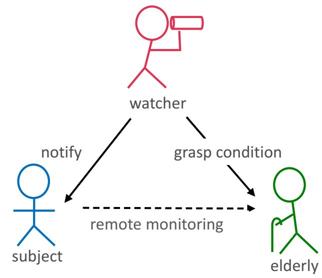

Fig. 1. Three-actor model

we confirm that the elderly state model works well. Second simulation, we aim to check the relationship between the monitoring sensor accuracy and elderly model. Finally, we have the goal to show how should remote monitoring sensor be accuracy. The simulation results show us that if the accuracy of monitoring sensor would be greater than 0.9990, the RMS could accuracyly detect the elderly state.

II. Preliminaries

A. Three actor model:A Modeling Framework of remote monitoring service

Figure II shows the three-actor model. Which we have previously proposed[5]. In this model, we can generalize various remote monitoring services by three actors (called a subject, a watcher, and an elderly) and relationships among the actors. The subject monitors the elderly people living in remote. A typical example of a subject is a family of the elderly people or a caregiver. The watcher can be a human or machine. The watcher of human would be a mailman or an employee of a monitoring service provider. Also, the watcher of machine represents a system, which monitors the elderly people by some sensors. Finally, the elderly represents a abstracted elderly person who is monitored by a subject via a watcher.

B. Modeling of elderly

Figure II-B shows a transition model of elderly healthy state. Specifically, elderly model has two kinds of states (i.e. normal, ill). Focus the left of the figure II-B, q_0(normal) shows that elderly state is healthy. In addition, if the elderly state is normal, which moves from a normal state to ill state with the probability q_{01}. Also the elderly state similarly moves other states with the probability 2,

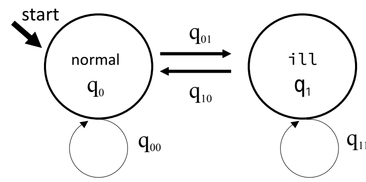

Fig. 2. Elderly State Model

3 and 5, which depends on the current elderly state. In the following, we show the each of transition algorithms.

$$q_{01} = \alpha + b * f(t) \tag{1}$$

$$f(t) = t.div(period) \tag{2}$$

First, we explain about formula 1. The left hand q_{01} means the probability of transition. The elderly model moves from a healthy state to ill state with the probability of q_{01}. The right value α means the initial probability of transition. Also the α would be $0 < \alpha < 1$. In addition, the right hand $b * f(t)$ means the aging function. We design the aging function if the model has aging then the possibility of becoming ill, is increased. Because, the elderly become more ill than other generation. Show the right value b, which means an aging parameter. If the b becomes increased, the elderly become more ill. The right value $f(t)$ means a function which periodically has increased. Besides this, the above function of argument t represents a timeline. The formula 2 shows the $f(t)$ in detail. For example, we assume $period = 30$, $t = 65$, then $f(65) = 65.div(30) = 2$. Finally, we can calculate that $q_{01} = \alpha + b * 2$.

$$q_{10} = \gamma - b * f(t) \tag{3}$$

Next, we explain the formula 3. The left hand q_{10} represents the probability of transition. Specifically, if the current elderly state is ill, then the elderly model transits the state of ill to normal at the probability q_{10}. In addition, if the elderly state is normal, which moves from a normal state to ill one with the probability of q_{01}. In formulas 1,2 we have similarly designed the elderly model that the possibility to become normal is decreased if the elderly model has aged. Based on previous thought, we design the probability which represents the elderly state moves from ill to normal. The right value γ represents an initial probability which would be $0 < \gamma < 1$.

Moreover, the $-b * f(t)$ is a function which means the decrease of probability to move normally. As well as this, it is a same function that we previously explained formula 2. While we design the aging that the possibility to become normal is decreased, we define the probabilityq_{10} is decreased by $b * f(t)$.

$$q_{oo} = 1 - q_{01} \tag{4}$$
$$q_{11} = 1 - q_{10} \tag{5}$$

Formula 4, 5 represents the probability which the elderly state stays the same state. We can calculate the probability to stay the same state with the probability of transition(i.e. q_{01}, q_{10}). For example, in formula 4, we can calculate how probability the elderly model stay normal. Also, the formula 5 represents a probability the elderly model stay ill.

C. Modeling of watcher

The watcher is an actor which has a role to monitor the elderly. Specifically the watcher obtains elderly condition with monitoring sensor, also the watcher notifies the subject about elderly state. In our model, we suppose that the watcher obtains using motoring sensor. Also, we suppose that the watcher can estimate the elderly state using the data with which the watcher obtains by monitoring sensor. As the above condition, we define the watcher's algorithm II-C. In the following, we explain the algorithm from top to bottom. First, the watcher has an interface we call it *periodicMonitor*. Concretely, the interface has an argument t which means that how periodically the watcher monitor the elderly people.

The line number of 3, $estimateEldelyState()$ is a function to estimate the elderly state, Specifically, this function estimates whether the elderly state is normal or ill. In this paper, we focus that the watcher can estimate the elderly state by sensor which has some accuracy. Therefore, we don't care a technology of implementation that how the RMS has implemented. We only focus on the accuracy of sensor. In the $estimateEldelyState()$, the $accuracy$ is an argument which represents the accuracy of monitoring sensor. Also, the $accuracy$ would be $0 < accuracy < 1$. Let us consider an example, we assume that the $accuracy = 0.85$ would be, if the watcher estimates the elderly by 100 number of times. Then, the result would show that the watcher detects 85 number of times in accuracy. On the other hand, the watcher fails to detect 15 number of times. Finally, if the watcher estimate the elderly people as ill, then the watcher notify the elderly state as ill subjects. Thus, we could actualize the role of the watcher in a simple way.

Algorithm 1

```
1: periodicMonitor(t)
2: if time.mod(t) == 0 then
3:     s = estimateElderlyState(accuracy)
4:     if (s==ill) then
5:         notify
6:     end if
7: end if
```

III. SIMULATION AND EVALUATION: REMOTE MONITORING SERVICE SENSOR SIMULATION

A. Abstract of Simulation

Our reaarch goal is to reveal how should remote monitoring sensor be accuracy. As an approach to reveal the above question, we developed the remote monitoring service simulator based on the model which we explained in section II. Using developed the simulator, we conduct a simulation with three types of elderly model (healthy, normal, sickly) and some remote monitoring accuracy. We also conduct three types of simulation with the simulator. In the first simulation (III-C), we confirm that the proposed elderly model works well. Second simulation (III-D), we confirm a relationship between the monitoring sensor accuracy and the elderly model. Third simulation (III-E), we confirm how should remote monitoring sensor be accuracy.

B. Settings of Simulation

We set five conditions so that we can simulate in a relatively simple way.

1) The elderly model cannot notify their ill to family by themselves. Thus the elderly is monitored by remote monitoring sensor.
2) The watcher monitors and estimates the elderly state with the accuracy of sensor which we give before the simulation.

3) The accuracy of remote monitoring service (called detectionPower) is calculated by the percentage of false detection.
4) We set a simulation term as four years (i.e. 1460 days) in every simulation.
5) Each simulation, we conduct some trials. The number of trials in simulation is 100 times. Also, we use the average value as the simulation result.

In the following, we explain the settings of simulation in detail. The first condition represents that the elderly model is monitored every day. We assume that the elderly is automatically monitored by watcher once-daily day with like physical sensor. The second condition means that we can set the accuracy of monitoring sensor in the simulation. Specifically, if the accuracy would be 0.9000, then we conduct ten times of simulation. We will obtain the simulation result that the remote monitoring service will fail to detect one time. For example, the fail means that the elderly state is ill, but the monitoring sensor detects as normal. The third condition shows that how to define the good remote monitoring sensor. Moreover, we calculate the power of remote monitoring service (we call the power *detection-Power*) in each simulation. The fourth condition represents the term of simulation. We assume that in the simulation the elderly is monitored in four years. Finally the fifth condition shows the number of trials. Each simulation we conduct some trials. The number of trials in simulation is 100 times. Furthermore, we calculate the average of detection power in the simulation.

Finally, we explain about implementation of simulator. We developed the simulator with programming language Java. The development effort was man-month and the total line of code was 1,246.

C. simulation 1: Confirmation of Elderly model

As mentioned above, the goal of this simulation 1 is that we confirm that the proposed elderly model works well. As the simulation result, we suppose that the elderly model works well, then if we set the more aging parameter b, then we would confirm that the elderly might be sickly because of the aging parameter. So we confirm that as the parameter become more larger, then the model become more sick. In this simulation we confirm the three type of elderly model (healthy, normal, sickly) which has individual aging parameter. For the purpose of illustration, we define three elderly model has each aging parameter $b_{healthy} = 0.0001, b_{normal} = 0.0010, b_{sickly}$=0.0030. The aging parameter has a next relationship $b_{healthy} < b_{normal} < b_{sickly}$. Thus the sickly elderly model become more sick than normal one. Remember that the elderly model has the initial value α, γ. The table III-C show the simulation initial value in the simulation.

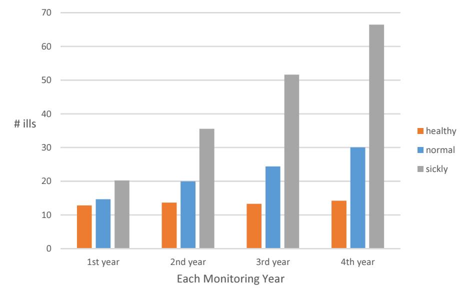

Fig. 3. Result of simulation 1: confirmation of elderly model

	before State	next state	same state
normal (q_0)	NONE (q_{01})	0.03	0.97
ill (q_1)	0.85	NONE	0.15

TABLE I. THE SETTING OF INITIAL AGING PARAMETER

Figure 3 shows the result of simulation. X axis means the each year whom the elderly has spent, and y axis represents the frequency of ill. From the figure 3, we can confirm that each type of elderly has become more ill. For example, the normal elderly model become more ill than second years. Also in the second year the number of ill is about 20% and in the third year the number of it is about 25%. So the third year become more ill than second year. Likewise we confirmed that the more elderly model has been aging, the more elderly model become ill. Above conclusion could apply the all three types of model which we defined. Consequently, we can confirm that the elderly model works well.

D. simulation 2: relationship between the monitoring sensor accuracy and elderly model

In the second simulation, the goal is to confirm the relationship between the monitoring sensor accuracy and elderly model. We conduct the simulation with the three types of elderly model which we explained in simulation III-C. Moreover we define the accuracy of remote monitoring service as $detectionPower$. Using $detectionPower$, we can use how accuracy the remote monitoring service. The formula 6 shows how to calculate the $detectionPower$. We use the detectionPower to evaluate the RMS power. Because, the accuracy of the sensor would calculate by some existing method, but we have to consider the total evaluation of RMS. The total evaluation of RMS is calculated by how the sensor detects accurately.

$$detectionPower = \frac{TrueDetect}{TrueDetect + FalseDetect} \quad (6)$$

In the formula 6, the right value $TrustDetect$ represents the frequency which the monitoring service estimates the elderly state correctly. Specifically the correct means that if the current elderly state and the state the monitoring service estimate is same. Although, the $FalseDetect$ means ,the remote monitoring sensor estimate it normal, however the current elderly state is ill. Recall that our setting of simulation, the elderly model is monitored each day and the term of the simulation is 1,440 days. Also, we conduct the simulation the three types of monitoring accuracy 0.80, 0.90 and 0.95.

Figure 4,5 and 6 show the results of simulation. X axis shows the elderly model (i.e. healthy, normal and sickly) and y axis means $detectionPower$. Moreover we define $detectionPower_{elderlymodel}$ to show the result of simulation. For example, in a case the result of simulation of healthy elderly, we can define the result as $detectionPower_{healthy}$. The figure 4 shows the result of simulation with the monitoring accuracy is 0.80, we understand that the $detectionPower_{healthy}$ is least in the figure 4. The result means that although the accuracy of monitoring sensor is not so low (0.80), the $detectionPower_{healthy}$ is low. This is because the accuracy of monitoring sensor is 0.80, so that the sensor faultily detect the elderly state. The frequency of ill is basically lowest in the elderly models, so it causes the decrease of $detectionPower_{healthy}$. The sickly model has been more ill than other model that cause the increase of $detectionPower_{sickly}$. Therefore, the result shows that $detectionPower_{sickly}$ is the highest score.

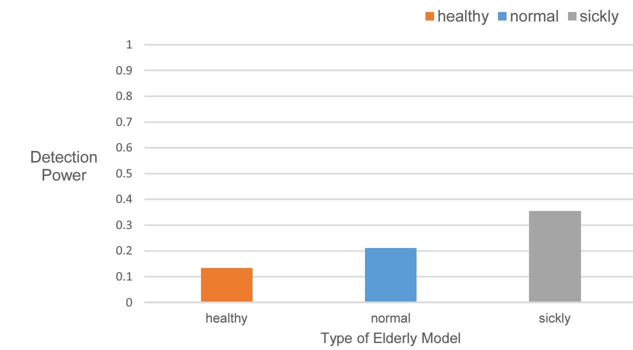

Fig. 4. Result of simulation 2: accuracy of monitoring sensor is 0.80

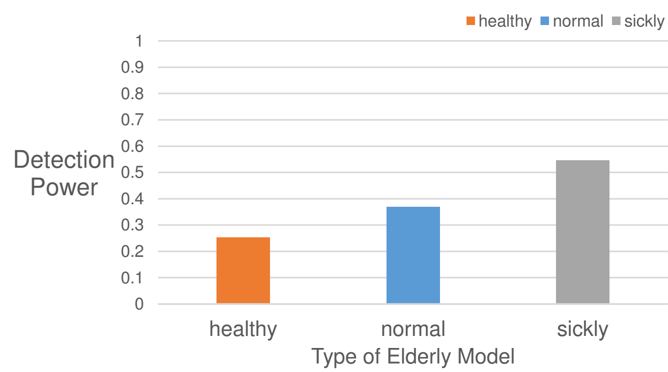

Fig. 5. Result of simulation 2: accuracy of monitoring sensor is 0.90

We can probe the relationship between elderly model and accuracy of monitoring sensor. When we give some accuracy to the monitoring sensor, then we could lead the following relationship 7. We denote the detectionPower as dP to simplify.

$$dP_{healthy} < dP_{normal} < dP_{sickly} \quad (7)$$

Moreover, we also understand as the accuracy becomes much higher, the $detectionPower$ become high score.

E. simulation 3: How should Remote Monitoring Sensor be accuracy?

The third simulation (III-E), we have the goal to understand how should remote monitoring sensor be accuracy. Our approach is to simulate by increased the accuracy of monitoring service from 0.9000 to 0.9999. In addition, we simulate using the same elderly model in simulation III-C, III-D. Figure 7 shows the result of simulation. X axis shows the accuracy of monitoring service and y axis means $detectionPower$. First we understand that

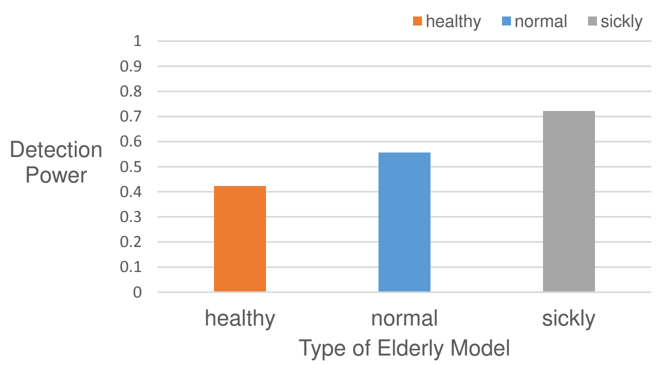

Fig. 6. Result of simulation 2: accuracy of monitoring sensor is 0.95

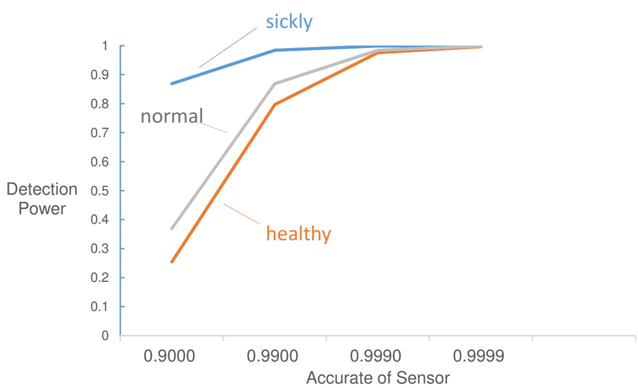

Fig. 7. Result of simulation 3: Transition of $detectionPower$ and accuracy of monitoring sensor

the most high score is the sickly model which is 0.8700. On the other hand, the least score is the healthy model (0.2544). Therefore there are much difference between the score of sickly model and that of healthy model. However if we set an accuracy as 0.9900, then the $detectionPower$ become greater than 0.7500. Moreover, the accuracy would be greater than 0.9990, the $detectionPower$ become nearly 1. Consequently, in our simulation if the accuracy of monitoring sensor would be 0.9990, the RMS provides high quality service for any kinds of elderly model.

IV. Discussion

With the results of simulations III-C, III-D, III-E, we discuss about how remote monitoring service should be. If we could set the accuracy of motoring sensor, the sensor could accuracyly estimate the elderly. However if the monitoring would be in a long term, then the $detectionPower$ has been decreased. Especially, $detectionPower$ become worse if we set the simulation conditions that the monitoring for the healthy elderly model. At the view point of end-user, the false detection in remote monitoring service would annoy them. Therefore, if the monitoring sensor could not be much higher, the service provider has to need ingenious method to keep the monitoring quality. For example, if the service provider could provide double monitoring method, then the provider could keep up the high quality of service. Concretely, as the first monitoring, some watcher monitors the elderly with some sensor (e.g. vital sensor). The second step, if the sensor detects the abnormal of the elderly, then the watcher notifies to call center which the service provider have. Moreover the call center confirms the elderly state with a camera which has previously set by the provider. Finally, if the elderly are really abnormal, then the call center notifies to elderly's family and emergency unit. This method would keep up high the remote monitoring service, if the accuracy of monitoring sensor wouldn't be much higher.

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References

[1] David M cutler et al. An aging society: Opportunity or challenge? *Brookings Papers on Economic Activity*, 1990(1):pp. 1–73, 1990.

[2] Ann Bowling, Zahava Gabriel, Joanna Dykes, Lee Marriott Dowding, Olga Evans, Anne Fleissig, David Banister, and Stephen Sutton. Let's ask them: a national survey of definitions of quality of life and its enhancement among people aged 65 and over. *The International Journal of Aging and Human Development*, 56(4):269–306, 2003.

[3] Philips. Medical alert service. http://www.lifelinesys.com/.

[4] Jae Hyuk Shin, Boreom Lee, and Kwang-Suk Park. Detection of abnormal living patterns for elderly living alone using support vector data description. *Information Technology in Biomedicine, IEEE Transactions on*, 15(3):438–448, 2011.

[5] Seiki TOKUNAGA et al. Modeling of remote monitoring service for elderly people. In *The 9th World Conference of Gerontechnology*, volume 13, pages 289–289, 2014.