Abstract

Healthcare is important to people, especially to elderly people who live independently. Since Internet services are getting reliable and stable, the tele-healthcare systems built on the Internet can be good supports to the traditional home healthcare centres and hospitals. The Internet-based tele-healthcare systems use Internet and specific modules can decrease the healthcare costs for patients and organization; can relieve the health professional shortage (at all levels) and the limit of institutional beds situations; and, can reduce unnecessary medical facility visits as well as examinations. Furthermore, such systems can reduce time costs, for instance, elderly people don't need to travel to the hospitals just for figuring out their health conditions. This research uses state-and-transition graph to analyze and build tele-healthcare system. The state-and-transition graph makes the healthcare process such as the care-giving tasks and status become crystal clear, and the token-based flow can help the care service providers (e.g. healthcare organizations and caregivers) ensure that the correct care services/actions have given at right time as well as avoid the possible mistakes which may be made by caregivers accidentally. With the proposed tele-healthcare system, elderly people can do physical examinations alone at home. The examination data is sent to the tele-healthcare server via Internet for analyzing and the health condition is categorized into different alarm levels. The system then arranges correspondent care services/actions for the elderly people automatically. A pilot has been done in a Care Centre of Elderly People in Taiwan.

Keywords

Healthcare, Non-intrusive physical examination, Westgard Multi-Rule Quality Management, Telemedicine, X-Chart, Levey-Jennings Control Chart

Motivation and Contributions
Recently, life conditions and medical technologies are getting better and people's average ages are older than before. Most of developed countries have accepted the age of 65 or older as being "elderly" (WHO, 2008). According to the report by Director-General of Budget, Accounting and Statistic (DGBAS) in Taiwan, the percentage of the elderly people (age 65+) in Taiwan in 1989 was 5.96% and the percentage has now reached 10.75% (January, 2011) of the total population (Director-General of Budget, Accounting and Statistic, 2011). This situation also happens in Canada. The percentage of the elderly people has increased from 1920's 6.68% to 2010's 14.13% of the total population in Canada (Statistics Canada, 2011a). Statistics Canada estimates that the population will increase to 37,057,100 by 2016 with a staggering 6,000,100 men and women aged 65 or older (Statistics Canada, 2011b). This translates into 16.19% of the country’s population at or above retirement age.

Hence, more and more researchers focus on solving the problems that an aging society may have, e.g. the elderly people might not obtain suitable care services/actions at the right time from their family members, the shortage of health professionals such like doctors and caregivers, and the cost of medical resources. In order to solve these problems, the care organizations are investigating a more efficient way to deal with the care requests. The care requests, for instances, elderly people may need to ask doctors or caregivers to examine their health conditions and/or to explain their health conditions for them in either hospitals or at their homes.

Internet services are getting reliable and stable in this decade. There are many medical organizations using computers and Internet technologies to deal with the care requests, this kind of systems are treated as tele-healthcare systems. Using the tele-healthcare system is easier for the care organizations to reduce the costs caused by the shortage of health professionals and caregivers, because of the caregivers and doctors can monitor the health conditions of the elderly people remotely (Collen, 2000; Kun, 2001; Kart, Moser, & Melliar-Smith, 2008; Karl, Finkelstein, & Robiner, 2006; Lee, Hsiao, Chen, & Liu, 2006; Zhu, Ahuja, Wu, Dauterman, Chen, Sukalac et al., 2008). Such a system allows the caregivers to retrieve the elderly people’s health conditions remotely and to take appropriate care actions at right time (Kahn & Sheshadri, 2008; Maglaveras, Chouvarda, Koutkias, Gogou, Lekka, Goulis, et al., 2005; Stantchev, Schulz, Hoang, Ratchinski, 2008). In summary, such a system benefits to doctors, caregivers, and elderly people, e.g. doctors can get clear picture of the health conditions of the elderly people who have chronic diseases; caregivers can avoid taking unnecessary care actions and spending a lot of time in travel between the care facilities and the elderly people's homes; and also, the elderly people do not need to go to the hospitals often.

In order to develop an ideal tele-healthcare system, there are at least three issues needed to take into our considerations. The first issue is how to reduce time costs and manpower (Collen, 2000). The second issue is how to get the elderly people’s health conditions. There are two kinds of medical examination instruments: non-intrusive and intrusive instrument. This research uses non-intrusive instrument to get the elderly people’s physical examination data. The non-intrusive instruments are usually used to detect and measure physiology signals, e.g. blood pressure, electrocardiogram, and breathing frequency. The third issue is how to ensure the elderly people received appropriate care services which are supposed to be given by the caregivers.

This research uses two methodologies to build such an ideal tele-healthcare system. First of all, we use state-and-transition graph to analyze and design a tele-healthcare system. The system shows the elder’s health conditions to the caregiver and helps the caregiver take appropriate actions of the elder. Second, we use X-chart and Westgard multi-rule quality management to analyze the elderly people's physical examination data and to categorize their
health conditions into different alarm levels for reminding medical professionals to take actions and reducing the chance of false alarm generation at meanwhile.

The rest of this paper is organized as follow. Section 2 introduces the state-and-transition graph and quality management. Section 3 defines the four alarm levels and describes the detailed processes of how the state-and-transition graph based tele-healthcare system works. The system architecture will be introduced in Section 4. At the end, Section 5 first uses a complete example to show the workflow of the tele-healthcare system, and then reveals how the system really works in a sanatorium in Yunlin, Taiwan. Section 6 does a simple conclusion.

**Backgrounds for Designing and Developing Tele-Healthcare System**

Some researchers find that people who have chronic diseases in the hospital need to spend a lot of time for traveling between their homes and hospitals and require medical resources for monitoring and healthcare (Emanuel, Fairclough, Slutsman, Alpert, Baldwin, & Emanuel, 1999; Karl, Finkelstein, & Robiner, 2006). Many researchers build healthcare information management systems for people like that. Such application indeed improves people's life and healthcare conditions, also provides people a better medical environment (Collen, 2000).

Emanuel and colleagues (1999) propose four care services: nursing care, transportation, homemaking, and personal care services. In order to deliver the requested care services to the people and save the manpower and medical costs, this research gives the caregivers the ability of taking appropriate care actions by defining the care actions and using a state-and-transaction graph. This research also uses the quality control and management to define four alarm levels for representing people's health conditions.

Petri net is a mathematical representation of discrete distributed systems. It was invented by Carl Adam Petri in 1962. Petri net has been used in many different domains such like performance evaluation, communication protocols, fault-tolerant systems, programmable logic, VLSI arrays, discrete event systems, decision models, and office-information systems.

There are three elements in Petri net: state nodes $s_i$, transition nodes $t_j$, and directed arcs connecting states and transitions (Peterson, 1981). States may contain any number of tokens. When the transition condition is satisfied, the token will move from one state to another.

Figure 1 shows a Petri-net example in which there are four states: $s_1$, $s_2$, $s_3$, $s_4$, and three transitions: $t_5$, $t_6$, $t_7$. The token starts at the state $s_1$ and should move to other states through the transition $t_5$. When $t_5$ is triggering, the token would be transfer to either states $s_2$ or $s_4$. The further details of how Petri-net works will be explained later by Figure 4.
This research alters Petri nets to build the state-and-transition graph to represent how the elderly people’s health condition changes trigger specific care actions and how the caregivers’ behaviors trigger specific system reactions. The detailed descriptions and explanations will be introduced later in Section 3.3.

There are four standard quality control charts: (1) Mean Control Chart (X-Chart), (2) Range Control Chart (R-Chart), (3) Twin Plots Method (Twin plot), and (4) Cusum Control Chart (Cusum chart). X-Chart calculates the mean value (X) and the standard deviation (SD) of collected data, produces a chart of relations between X and SD. Levey and Jennings (1950) are the first researchers using X-Charts for the clinical examination. After that, using X-Chart in the clinical examining has become an important method.

There are four problems may happen when we use quality control charts: (1) immaturity of working techniques, (2) a bad of measurement instruments, (3) a change of reaction condition, (4) an error of computation. Because of X-Chart is a single value model which can possibly cause immaturity of working techniques and bad measurement instruments. Westgard and colleagues propose a multi-rule way to improve X-Chart applications and can be also used in unusual data measurements (Westgard, Barry, Hunt, & Groth, 1981; Westgard & Barry, 1986). Westgard rules are summarized as:

(1) When a single examination value goes beyond the range between \( X + 2SD \) and \( X - 2SD \), we must check it again or apply the following rules.

(2) When a single examination value goes beyond the range between \( X + 3SD \) and \( X - 3SD \), this examination result would be abandoned and re-examination is needed.

(3) When two continuous examination values go beyond the range between \( X + 2SD \) and \( X - 2SD \), it might be a system error and the result would be abandoned.

(4) When the difference between two examination values is 4SD, it possibly a random error and this result would be abandoned.

(5) When four continuous examination values go beyond the range between \( X + SD \) and \( X - SD \), it might be a system error and the result would be abandoned.

(6) When ten continuous examination values are all higher than the mean value or lower than the mean value, it might be a system error and the result would be abandoned.
This research uses both of X-Chart and Westgard Multi-Rule Quality Management to define the alarm levels of the elderly people’s health conditions and the rules of care giving.

**Tele-Healthcare System Analysis**

Maglaveras and colleagues (2005) conclude that tele-healthcare systems should have four functions:

1. **Measurement**: patients can upload their health conditions by using tele-healthcare instrument at home. Medical personnel can take appropriate care actions after analyzed the patients' health conditions.

2. **Communicative**: patients can communicate with medical personnel and/or professionals (e.g. doctors) with tele-healthcare systems via emails, short messages, instant messengers, and VoIP (voice over IP) phone calls.

3. **Interactive**: patients can use tele-healthcare systems to see their medical data (e.g. electrocardiogram) and realize their health conditions, also, the systems can deliver the care requests to appropriate care givers for the patients and send emergency care action requests to appropriate care givers according to the patients' health conditions, so the patients can get right medical care service at right time.

4. **Educational**: patients can use tele-healthcare systems to get information and/or education materials such like blood sugar control plan to improve their health conditions on their own.

Two roles, patients and caregivers, are taken into consideration in the proposed tele-healthcare system. The patients could be mentally ill, physically disabled, health condition is impaired by sickness and aging, however, this research and corresponding pilot mainly focus on elderly people. The caregivers are taking care of the patients and may be the patients' family members or volunteers.

In this research, the tele-healthcare system has two subsystems: tele-physical examination subsystem and tele-care subsystem. The main function of the tele-physical examination subsystem is to allow elderly people to do physical examinations by themselves at home and to upload the examination data to the healthcare organizations via the Internet. The tele-physical examination subsystem is mainly designed to reflect the measurement function that a tele-healthcare system should have. Moreover, the subsystem will provide the patients additional information and materials based on its examination results, the subsystem also has the above mentioned educational function.

The main function of the tele-care subsystem is to notify the caregivers taking appropriate care actions at right time according to the elderly people's health conditions. The tele-care subsystem therefore is mainly designed to reflect the interactive function that a tele-healthcare system should have. In many situations, the subsystem generates and delivers required care action requests to the caregivers for the patients, which makes the communications in-between...
the patients and the caregivers happen. In some cases, the caregivers will be asked by the subsystem to help the patients book an appointment with the doctors, which allow the patients to communicate and discuss their health conditions with the doctors. The subsystem therefore has the above mentioned communicative function.

The proposed tele-healthcare system hence has all the four functions that Maglaveras and colleagues concluded in 2005. Due to the communicative function can be reached by any kind of information communication technologies and the educational function is relatively easier to implement if compared with the other three functions, we put more efforts on the other two functions in this research. So the rest of this paper mainly focuses on the two functions that a tele-healthcare system should have, i.e., measurement and interactive function.

It is important for a tele-healthcare system to know which health condition a patient has according to his/her examination data. The state-and-transition graph is a good methodology to analyze and represent the health conditions of the patients. We design three modules in these two subsystems: measurement module (in tele-physical examination subsystem), care action arrangement module and action module (in tele-care subsystem), for reaching this goal.

**Tele-Physical Examination Subsystem**

This research uses two quality control methods, X-Chart and Westgard Multi-Rule, to decide the alarm level of a patient's health condition and the alarm timing. An alarm has four levels: normal (A), subnormal (B), cautious (C), and alert (D). Alarming levels are decided by X-Chart based on the mean values (X) and standard deviations (SD) of the patient examination data (Tseng, Lin, Cheng, Heh, & Lo, 2007).

After getting the mean value and standard deviation of the examination data, the top limit is set as $X + 3SD$ and that bottom limit is set as $X - 3SD$. In other words, the data in the range between $X + 3SD$ and $X - 3SD$ is called action limit as Figure 2 shows. If the patient's examination data go beyond the limit, then Westgard Multi-Rule may recheck the patient's examination data for triggering the care actions. The data falls into the range between $X + 2SD$ and $X - 2SD$ will be seen as an "alert".

![Figure 2 Action limit](http://ci-journal.net/index.php/ciej/article/view/762/900)
The range between $\bar{X} + 2SD$ and $\bar{X} - 2SD$ is warning limit as Figure 3 shows. If the patient's examination data go beyond the limit, then the caregiver should take appropriate care action for the patient. If the patient's examination data falls into the warning limit, then the system will send the message to the patient and ask him/her to pay attention on his/her related health condition.

![Figure 3 Warning limit](image)

The warning limit includes three alarms levels: normal, subnormal, and cautious. The range between $\bar{X} + 1.5SD$ and $\bar{X} + 2SD$ or between $\bar{X} - 1.5SD$ and $\bar{X} - 2SD$ are "cautious". The range between $\bar{X} + SD$ and $\bar{X} + 1.5SD$ or between $\bar{X} - SD$ and $\bar{X} - 1.5SD$ are "subnormal". The range between $\bar{X} + SD$ and $\bar{X} - SD$ is "normal" and the caregivers do not need to take any care actions for the patients.

This research revises Westgard multi-rule quality control to generate appropriate care rules for the physical-examination subsystem and adopts X-Chart norms at the same time. Electronic instrument may have random errors: (1) the single examination record is greater than $\bar{X} \pm 3SD$ and (2) the difference between two continuous examination records are larger than 4SD. These errors in the physical-examination subsystem are considered as the incorrect examination data and will be dropped.

**Tele-care Subsystem**
Figure 4 Measurement module in the tele-care subsystem

Figure 4 shows the process of the patients use the measurement module to do physical examination and get reminders from the system if they forgot doing the examinations. Initially, the system is halt at state $s_1$. The transition $t_1$ will be triggered and the system asks the patient registering and filling out his/her personal information. At state $s_2$, the patient shall do the physical examination by himself/herself at home.

Two situations might happen at state $s_2$. First, the patient does the physical examination and the transition $t_2$ will be triggered. In this case, after the patient finished his/her physical examination, the transition $t_6$ will be triggered and the system analyzes the examination data and decides the alarm level. On the contrary, if the patient does not do the physical examination in specific time period, the transition $t_3$ will be triggered and the system goes to state $s_4$ to remind the patient doing physical examination. If the patient does not do physical examination over a week, the transition $t_4$ will be triggered and the system will send message to the patient to remind him/her again. At the end, the system goes back to state $s_1$ and repeats the physical examination process. We intended to not using $t_5$ to name the transition here due to we have two identical transitions - "sending the reminder to patient" in Figure 4.

### Table 1 Pre-conditions and actions of transitions in Figure 4

<table>
<thead>
<tr>
<th>Pre-Condition</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$ The patient filled out the personal information</td>
<td>Begin examination</td>
</tr>
<tr>
<td>$t_2$ The patient starts doing the physical examination.</td>
<td>Decide result</td>
</tr>
</tbody>
</table>
The patient didn't do the physical examination in a time period. | No examining
---|---
The patient still didn't do the physical examination over a week. | Send a message to remind the patient
The patient finished the examination. | Decide the alarm state

Table 1 shows the conditions of all transitions in the measurement module (Figure 4). After the system decides the alarm level for the patient's health condition, the caregiver will take appropriate care action accordingly. Figure 5 shows the care action arrangement module. Once the system receives the examination data, the system analyzes the data and decides the alarm levels for the patient. According to the alarm levels, the caregiver realizes what health conditions the patient has. There are four alarm levels: A, B, C, and D. The level 'A' indicate that the patient's health condition is normal and doesn't need any care service.

As Figure 5 shows, there are two tokens, \( m_2 \) and \( m_3 \), in this module. The token \( m_2 \) represents the alarm level of the patient. The token \( m_3 \) represents whether the caregiver has taken the care action for the patient or not. In Figure 5, after the transition \( t_6 \) triggered, the system goes to state \( s_6 \) to wait for the care action arrangement. The caregiver may (1) take appropriate care action for the patient according to the alarm level or (2) do nothing for the patient.

In the first situation, when the patient's alarm level is 'A', the caregiver may ask the patient to do another physical examination item, for instance, the patient has done the heart function examination and everything seems good, however, the caregiver could ask the patient doing another kidney function examination. The transition \( t_1 \) will be triggered and the system returns...
to state $s_2$ again. Also, the caregiver may provide related healthcare information according to the patient's health condition. The transition $t_7$ then will be triggered and the system goes to state $s_1$.

If the patient's alarm level is 'B', the transition $t_8$ will be triggered and the system goes to state $s_8$. The caregiver may take appropriate care actions, for example, arranging home healthcare service for the patient. The transition $t_9$ would be triggered and the system goes to state $s_9$. If the patient's alarm level is 'C', the caregiver needs to arrange the patient to do online diagnosis with the doctor. The transition $t_{10}$ is then triggered and system goes to state $s_{10}$. If the patient's alarm level is 'D', the caregiver needs to help the patient make appointment with the doctor at hospital. In this case, the transition $t_{11}$ will be triggered and the system goes to state $s_{11}$.

If the caregiver does not take any care action for the patient, the transition $t_{12}$ will be triggered and the system goes to state $s_{12}$. If the caregiver does not take any care action for patient more than two days, the transition $t_{13}$ will be triggered and the system goes to state $s_{13}$ and asks the caregiver taking a care action immediately for the patient. Table 2 lists the pre-conditions and actions of transitions in the care action arrangement module (Figure 5).

**Table 2 Pre-conditions and actions of transitions in Figure 5**

<table>
<thead>
<tr>
<th>Transition</th>
<th>Pre-Condition</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_1$</td>
<td>Ask the patient to do another physical examination</td>
<td>Examination</td>
</tr>
<tr>
<td>$t_6$</td>
<td>Finish the examination.</td>
<td>Decide alarm level</td>
</tr>
<tr>
<td>$t_7$</td>
<td>Finish the examination and get the alarm level.</td>
<td>Provide healthcare information</td>
</tr>
<tr>
<td>$t_8$</td>
<td>The alarm level has been found.</td>
<td>Arrange care actions</td>
</tr>
<tr>
<td>$t_9$</td>
<td>The caregiver has taken the care action.</td>
<td>Finish arrangement</td>
</tr>
<tr>
<td>$t_{10}$</td>
<td>The caregiver didn't take the care action.</td>
<td>No care action arrangement</td>
</tr>
<tr>
<td>$t_{11}$</td>
<td>The caregiver didn't take care action more than two days</td>
<td>Remind to arrange care actions</td>
</tr>
<tr>
<td>$t_{12}$</td>
<td>System sends an urgent request to the caregiver and asks s/he taking the care action.</td>
<td>Send a message about care action arrangement</td>
</tr>
</tbody>
</table>

Figure 6 shows the action module. Two tokens, $m_4$ and $m_5$, in this module. The token $m_4$ represents the alarm level of the patient's health condition and the token $m_5$ represents whether the caregiver have completed the care action(s) or not.
Figure 6 Action module in the tele-care subsystem

A caregiver may (1) has taken the care action or (2) doesn't complete the care action. If the caregiver completes the care action for the patient, the transition $t_{13}$ will be triggered and the system goes to state $s_{14}$. The caregiver is then asked to upload the care report to the system and the transition $t_{15}$ will be triggered to make the system go back to state $s_{1}$. If the caregiver does not complete the care action for the patient, the transition $t_{14}$ will be triggered and the system goes to state $s_{15}$ to remind the caregiver doing the care action. If the caregiver does not complete the care action in three days, the transition $t_{16}$ will be triggered and the system sends the message to the caregiver and asks him/her to complete the care action immediately. Table 3 lists the pre-conditions and actions of transitions in action module (Figure 6).

Table 3 Conditions of transition nodes in action module

<table>
<thead>
<tr>
<th>Condition</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{13}$  The caregiver has done the care action.</td>
<td>Finish care actions</td>
</tr>
<tr>
<td>$t_{14}$  The caregiver doesn't do the care action.</td>
<td>Finish no care actions</td>
</tr>
<tr>
<td>$t_{15}$  Tele-care subsystem received an action report.</td>
<td>Care report</td>
</tr>
<tr>
<td>$t_{16}$  The caregiver doesn't do the care action in three days.</td>
<td>Remind to finish care actions</td>
</tr>
<tr>
<td>$t_{17}$  Tele-care subsystem sends a reminder to the caregiver.</td>
<td>Send a message about executing</td>
</tr>
</tbody>
</table>
At the end of this section, Figure 7 below shows a complete state-and-transition graph of the proposed tele-healthcare system.
Figure 7 Modelling the tele-healthcare system with the state-and-transition graph.
Tele-Healthcare System Architecture

The tele-healthcare system architecture designed by this research can be divided into four parts according to the workflow. The four parts are Case, Execute, Server, and Monitor, as Figure 8 shows. The patients can make care service requests and the caregivers can take appropriate care actions. We describe the details from different viewpoints.

![Figure 8 Tele-healthcare system architecture](image)

Figure 8 Tele-healthcare system architecture

Figure 9 shows how the tele-healthcare system works for the patients. The patients can use the tele-physical examination subsystem to do physical examination by themselves. The examination data is then uploaded to the database via Internet directly and transparently. The alarm system receives the examination data from the tele-physical examination subsystem and stores it into the case database. The rule-based care system analyzes the examination data and automatically categorizes the patient health condition into one of four alarm levels: normal, subnormal, cautious, and alert.

![Figure 9 How the patients use the tele-healthcare system?](image)

Figure 9 How the patients use the tele-healthcare system?
The patients can have clear idea of their health conditions and relevant information within the system. For example, the patient who has a liver disease can get information such as “eating high-salinity food less and having sleep at right time” from the system.

On the other hand, caregivers can receive the patients’ health conditions from the case database within the tele-care subsystem as Figure 10 shows. The caregivers also take care actions for the patients and upload the action reports to the tele-care subsystem.

![Figure 10 How the caregivers use the tele-healthcare system?](image)

Figure 11 shows how care organizations and medical professionals such like doctors, caregivers, and administrative personnel use the tele-healthcare system.

![Figure 11 How care organizations use the tele-health system?](image)

A doctor can access the patient’s examination data (as Figure 12 shows) to get in-depth view of his/her health conditions such as cholesterol, blood sugar, and liver function.
Figure 12 Time-series of some diseases

The examination data is considered important to the medical professionals if:
1. two continuous examination records are alert;
2. three continuous examination records are cautious;
3. four continuous examination records are subnormal;
4. the average of four examination values is alert;
5. the average of six examination values is cautious; and,
6. the average of eight examination values is subnormal.

By using Westgard multi-rule quality control method, the caregiver can take different care action according to the patient’s alarm level. Table 4 lists the relations among Westgard multi-rules, alarm levels, and care actions which used in the proposed tele-healthcare system.

Table 4 Relations among Westgard multi-rules, alarm levels and care actions

<table>
<thead>
<tr>
<th>Statistics Method/Number</th>
<th>Alarm Level</th>
<th>Alarm Value</th>
<th>Care Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Continuous Examination Records</td>
<td>Alert</td>
<td>D</td>
<td>Make an appointment at a hospital</td>
</tr>
<tr>
<td>6 Continuous Examination Records</td>
<td>Cautious</td>
<td>C</td>
<td>Arrange online diagnosis with doctors</td>
</tr>
</tbody>
</table>
The caregiver needs to take appropriate care actions according to the alarm level of the patient's health condition. For examples, the caregiver can choose to arrange online diagnosis with doctors for the patient when his/her alarm level is 'C' or to make an appointment with the doctor at a hospital for the patient when his/her alarm level is 'D'. After the caregiver completes the care action, the caregiver needs to upload the action report to the system immediately.

From the care organization's viewpoint, the proposed tele-healthcare system benefits them in two ways. First, if some caregivers didn't take care actions in specific time period, the monitor will send a message to ask them doing the actions immediately. Second, caregivers have to upload the care action reports after they complete the actions, these action reports are not only considered as proofs of hard working, but also give the organizations an idea of when and what care actions have been taken.

**Complete Example and The Pilot**

**Complete Example**

In this example, there are patient, caregiver, and doctor. Stis is the patient, Alex is the caregiver, and Maiga is the doctor. Some parameters involved in the state-and-transition graph are defined, for example, the token $m_1$ in Figure 13 represents whether Stis takes a physical examination in a week. After Stis takes the physical examination and uploads the examination data to the database via the Internet, Stis gets information about his health conditions. If Stis doesn't take any physical examination for a while, the system will send message to Stis and ask him to do examination at home by himself. The message looks like: "Hello, [Stis]: it's a reminder. The records show that you haven't used the tele-physical examination system for a while. [Alex] hopes that you could do the physical examination as soon as possible. This reminder is sent on [2011/03/12] ".
After Stis takes the examination, the data is sent to the system. Alex will get an idea of Stis’ health condition. If Stis’ health condition is classified at the alarm level ‘C’, then Alex should take appropriate care action for him. Based on Table 4, Alex should arrange Stis doing an online diagnosis with Maiga (the doctor). If Alex does not arrange the care action for Stis, the system will send a message to Alex. The message looks like: "Hello, [Alex]: it's an alarm message about your patient, [Stis], whose liver function is at the alarm state [C]. Please take the appropriate care action for him/her. This message is sent on [2011/03/12]." Figure 14 shows the process of care action arrangement in Alex-Stis Case.

After Stis does an online diagnosis with Maiga, Alex needs to work with Maiga to conduct a diagnosis report. If Alex does not upload the action report in expected time, the system will send a message to ask Alex to upload the care action as soon as possible. The message looks like: "Hello, [Alex]: it's a message about your patient, [Stis], whose liver function is at alarm state [C]. The care action was arranged on [2011/03/12]. If you haven't taken any care action for him/her yet, you must take appropriate care action immediately. If you have completed the care action already, please upload the action report immediately. This message is sent on [2011/03/14]." Figure 15 shows the process of action module for Alex-Stis Case.
The System for Pilot

As we mentioned in Section 3, the tele-healthcare system has two subsystems: the tele-physical examination subsystem and the tele-care subsystem. Figure 16 shows the tele-physical examination subsystem and its sign-on window. The patients need to sign in the system and do physical examination by themselves at home with the non-intrusive physical examination pen as Figure 17 shows. The non-intrusive physical examination pen basically gathers the electronic data from particular points on the human body. Those points are called acupuncture points and are used in treatment based on the Traditional Chinese Medicine theory. The patients can do many physical examination items, e.g. kidney stone and liver function.
Figure 16 The patient needs to sign in the tele-physical examination subsystem before taking non-intrusive physical examination
Figure 17 Non-intrusive physical examination
After the patient does the physical examination, the system shows the alarm level for him/her (as Figure 18 shows). Also, at the bottom of the screen, the patient can find suggestions for his/her health condition.

**The Pilot in Yunlin, Taiwan**

In order to prove the state-and-transition graph is helpful to the tele-healthcare system, this research did a pilot in a sanatorium in Yunlin, Taiwan. The pilot asked the patients doing non-intrusive physical examination at least once a week at home. In addition, the sanatorium also designated five caregivers for the twenty senior citizens. Figure 19 shows partial results of the examination data analysis of the twenty senior citizens. There are five examination items they can do: liver function (i.e., the 3rd column), asthma (i.e., the 5th column), heart function (i.e., the 7th column), blood glucose value (BGLU) (i.e., the 9th column), and cholesterol (i.e., the 11th column).
Figure 19 Partial results of the examination data analysis of twenty senior citizens

Take the patient #5 as an example. The patient has the alarm level 'B' in his/her liver function, blood glucose value, and cholesterol. After the caregiver receives the alarm levels of his/her health conditions, the caregiver does care actions for the patient. We use his/her blood glucose data to show how the proposed tele-healthcare system runs (please refer to Fig 7).

(1) August 7:

s1 (didn't take examination)
s2 (didn't take examination)
s3 (took examination, alarm state is A)
s6 (don't need caregiver, alarm state is A) --> action report at 09:56 AM

(2) August 9:

s1 (didn't take examination)
s2 (didn't take examination)
s3 (took examination, BGLU's alarm level is B)
s6 (no action arrangement, alarm level is B)
s8 (no action arrangement, alarm level is B)
s9 (has action arrangement, alarm level is B, the caregiver doesn't do the care action)
s12 (has action arrangement, alarm level is B, the caregiver did the care action) --> action report at 09:45 AM

(3) August 15:

s1 (didn't take examination)
Conclusions

It is important to develop a tele-healthcare system for healthcare organizations, professionals, and patients. People can monitor and realize their health conditions with the system easily. Utilizing the state-and-transition graph to analyze the tele-healthcare system which we proposed in this research can clearly and simply show the relations between the patient’s health conditions and the caregivers’ care actions. In addition, the system can also remind the caregivers do appropriate care actions and monitor the care action activities.

Three differences between this research and previous tele-healthcare solutions: (1) the proposed system uses state-and-transition graph (altered Petri-net) to structure its flow and actions, the state-and-transition graph is not only easy to understand for everyone but also provides flexibility to organizations such as hospitals and healthcare centre to make the system fit into the regulations and the workflow that the organizations currently have; (2) the proposed model takes four different user groups - organizations, professionals (e.g., doctors), caregivers, and patients into consideration, which provides a much more complete tele-healthcare solution; and, (3) the internet based non-intrusive health condition examination method allows elders to do physical examination easily and no danger, in addition, the X-Chart and Westgard Multi-Rule based diagnosis method reduces the possibility that the system raises false alarms for elders’ health condition.

The proposed tele-healthcare system not only can save the costs of medical manpower and resources, but also can discover the patients’ unusual health conditions with the two quality control methods, X-Chart and Westgard Multi-Rule. At the next step, we are considering to integrate the mobile devices (e.g. smartphones and mobile phones) into the tele-healthcare system. For example, the mobile devices can access the medical examination instrument’s records via Bluetooth or USB interface and send the examination data to the tele-healthcare server at anytime and anywhere. In this case, the system can be a good support for preventative healthcare, moreover, the whole system will be non-stop health service as long as the patients have the wearable medical examination instrument and their mobile phones have turned on. Furthermore, the perceptions that elderly people and professional toward technology acceptance and satisfaction degree are needed to be investigated further.

References


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