MOBILE TIMELINE
Mobile Charting System that Provides a Graphical Summary of a Patient's Medical Record

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Abstract: In this paper, we introduce a novel medical information system that works on smartphones. This system provides chronological graphs of a patient's medications and medical examinations over an extended period of years as graphical summaries of the patient's medical history so that physicians can gain a clear understanding of the patient's status and develop treatment plans easily. In our system, we implemented the original algorithm that reduces the amount of medical data by merging adjacent data hierarchically when the time span for displaying the data is changed. By implementing this algorithm, the system proposed here was shown to be about 30 times faster than the system with a conventional method. Also, we evaluated our system through the experiment in medicine using real medical records. The results indicate that physicians would benefit significantly by using our system especially in situations where they cannot use another medical information system through their PC, such as the patient's bedside.

1 INTRODUCTION

In recent years, the use of mobile phones as a client device in medical information systems that display a patient's medical data has become increasingly popular (G.Benelli et al. 2010). Implementation of such systems promises significant advances in patient care because of their mobility and flexibility. This is because today's mobile devices, such as smartphones, now have the capacity for a variety of medical applications and can be used from any location (M. Watson 2006, J. Sammon et al., 2006, A. Kumar et al., 2009). For example, a system that allows physicians to see and share the electronic health records of their patients (G. Benelli et al., 2010, F. Andry et al., 2011) has been proposed. However, in order to diagnose a patient with a chronic disease such as diabetes, physicians often need not only recent medical data from the patient's medical record but also a chronological graph of the medications and medical examinations that the patient may have undergone over an extended period of years as a graphical summary of the patient's medical history. Since their overall treatment time is very long, physicians often use these graphical summaries to analyze and ascertain a patient's status and develop a treatment plan. While mobile devices are very flexible, it is extremely difficult for them to display a graphical summary because they do not have sufficient computing and processing capacities. In view of these problems, we propose a brand new mobile medical information system that overcomes these shortcomings (K. Ogawa et al., 2011). In this paper, we introduce actual implementations of the system and results of a small-scale experiment conducted at Tohoku University Hospital.

2 CONVENTIONAL MEDICAL INFORMATION SYSTEMS

In this section we give an overview of an EMR system and an electronic patient chart as examples of conventional systems used in medicine.

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2.1 Example of EMR System

Fig.1 shows an example of a conventional EMR system. This system has a user interface similar to legacy paper medical records and displays the patient's medical information for one day.

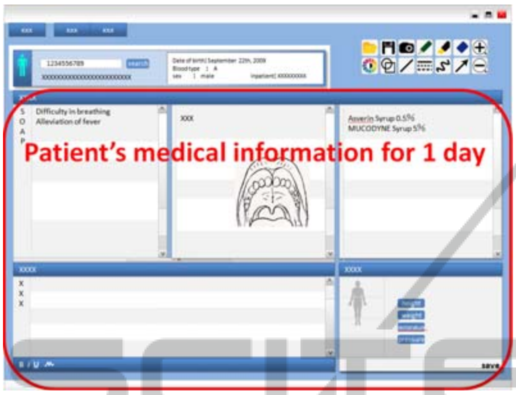

Figure 1: EMR system.

Such systems that present first-hand medical data obtained from a patient's medical record are also implemented on smartphones (F. Andry et al., 2011). However, physicians often need to analyze a patient's medical history over several years (H. Smith et al., 2006, G. L. Warnock et al., 2008). For example, to determine a treatment plan for diabetes, physicians must analyze medical data that have been accumulated over several years because the disease often progresses over a prolonged period. Therefore, the problem with this system is that it displays the medical data for only one day whereas the medical data physicians need to perform a proper analysis varies according to the patient and the disease.

2.2 Example of Electronic Patient Chart

Fig. 2 shows an example of an electronic patient chart system. This system allows physicians to analyze the medical information such as a patient's body temperature and blood pressure for a fixed period.

However, different kinds of medical data are generated over different intervals. For example, if a physician needs to analyze and determine the medications for a patient with diabetes who has the flu, the doctor must examine the changes in the patient over a long time span and investigate any contraindications to a possible drug therapy over a short time span. So the problem with this system is that physicians cannot analyze medical data and change the time span freely.

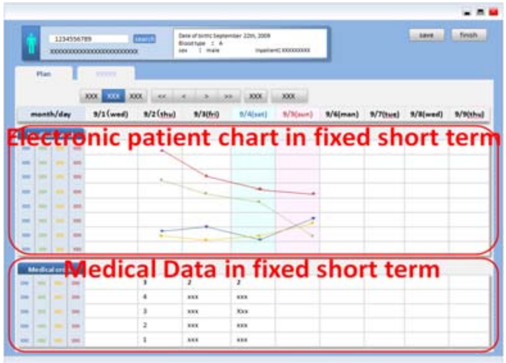

Figure 2: Electronic patient chart.

2.3 Limitations of Conventional Systems

To summarize, conventional systems are unable to sufficiently support the medical analysis that physicians need to conduct. This is because these systems do not have the ability to display the patient's chart for various diseases that occur over a range of time spans.

3 PROPOSED TIMELINE INTERFACE

As described in section 2, conventional medical systems have a problem in that they are unable to display the patient's medical chart over a range of time spans. Furthermore, there is an increasing need to be able to see patient medical data in locations not restricted to those where they can access a conventional medical system via a PC (M.Watson 2006, J.Smith et al. 2006, A.Kumar et al. 2009).

3.1 System Overview

In view of these problems, we propose a brand new system that consists of a server and an application on a mobile device. In this section, we introduce the system implementation that we developed for use in actual clinical practice. In our system, the server transmits the medical data from a conventional EMR system's server and optimizes it. An application on a mobile device displays the patient's medical chart with the TimeLine interface.

3.2 TimeLine Interface

The TimeLine interface has a function that displays a chronological chart of the patient's medical data over various time spans. By means of this function, medical data can be divided into categories called medical items. Medical items are, for example, types of medication or types of medical tests and so on. Also, under each medical item, there are numerous medical events that represent the medical services the patient has received as shown in Fig.3.

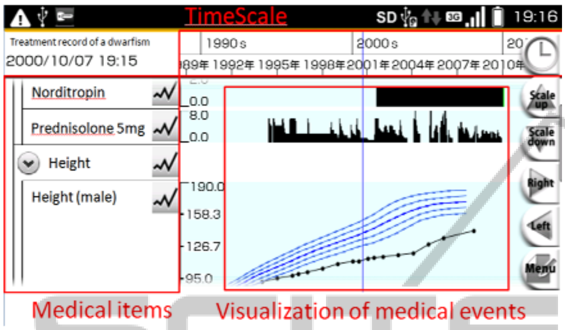

Figure 3: TimeLine interface.

Also, TimeLine has a multistage time scale of years, months, days, hours and so on. With the TimeLine interface, physicians can change the time scale and its length to display with a single easy operation such as pinch-in/pinch-out operations on a screen of a smartphone. For example, the time scale can be changed from hours to days or to months. By changing to a short time scale, physicians can analyze medical data over a short period in more detail. Conversely, by changing to a longer time scale, physicians can analyze medical records over a long period. Fig.4 shows the operation of time scales.

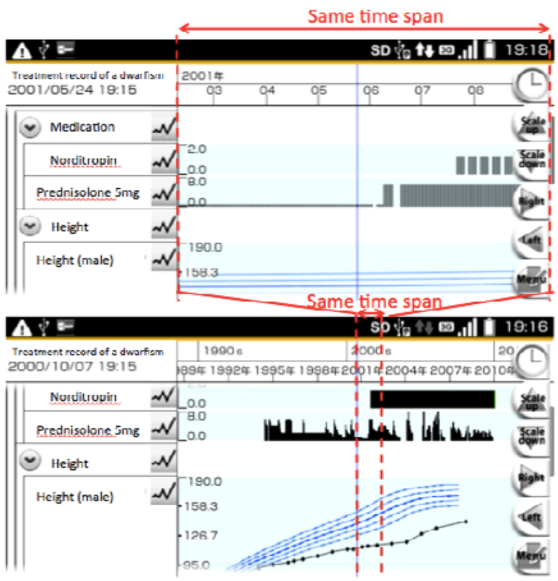

Figure 4: Time scale in TimeLine interface.

In this manner, physicians can analyze a range of a patient's medical history.

3.3 Adaptive Event Merge Algorithm

However, TimeLine requires the processing of a large volume of data and high processing ability to draw the charts because physicians tend to record a large number of medical events. Take the case of a patient with a chronic disease; medical events are generated over a period of time measured in decades. It takes a lot of time to process such large volumes of data; consequently, the response speed of our system goes down. So this is the most serious problem of TimeLine interface. The best way to solve this problem is to reduce the volume of data to process. In order to do this, we developed the *adaptive event merge algorithm* in TimeLine. The purpose of this algorithm is data reduction. Because of the resolution limit, if the user expands the time span to be shown, all the data plots are not displayed on the screen. Making use of this feature, the system can reduce the volume of data to process by reducing the data for each time scale. In other words, if the system can process only the visible data plots for display on a chart over a long time span, such as the time scale for a year or ten years, we can reduce the workload on the system. Now, the medical events that our system processes tend to consist of the data from medical inspections or medications generated once a day and once every month in average. So, the visible number of total data plots tends to vary for a time scale of a year or longer.

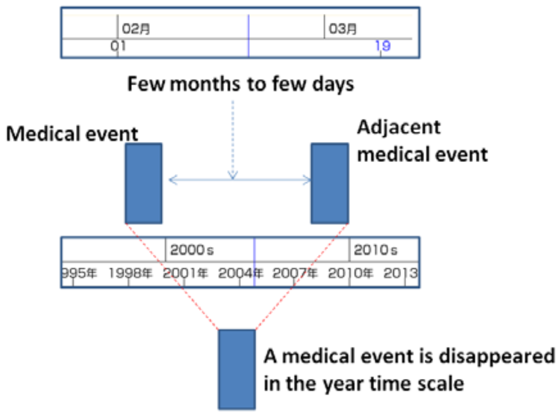

Figure 5: Typical medical events in our system.

So, we created several DB tables for various expansion rates across longer time spans, as well as the minimum number of data tables for shorter time spans. By using these DB tables, the system can process only visible data for each time span. In fact, we created the 20 data tables below:

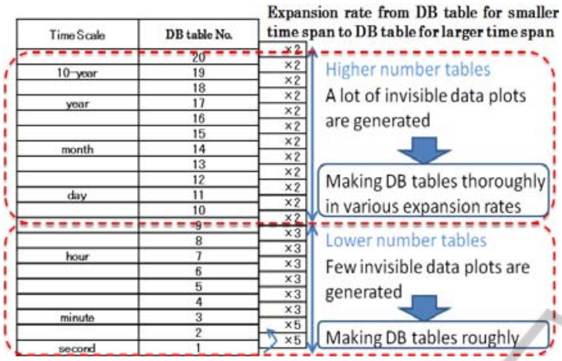

Figure 6: DB tables and expansion rates.

The lower numbered tables store visible data for shorter time spans (i.e. smaller expansion rates), on opposite, while the higher numbered tables store visible data for larger time spans. Also, the 3rd column means the expansion rates from lower numbered tables to higher numbered tables. As can be seen, these DB tables are designed so that the system can process the smaller number of data when the system represents the chart of larger time spans (i.e. the time spans that the number of visible data tends to change).

Now, we briefly describe the steps of this algorithm below:

1. The algorithm represents a medical event as structured data that includes the start time, end time, the value, and other factors.

2. For each expansion rate, the system calculates the distance to adjacent data objects using the formula below.
In the formula, we use d_n for the "nth" data object of a patient, ts_n for the start time, te_n for the end time, C for a coefficient, and E for the expansion rate between each DB table.

Formula: $$\frac{ts_n - te_{n+1}}{E} \cdot C$$

3. If the distance is smaller than the threshold, the system generates a new data object that represents the original two data objects. This threshold represents the distance that a person can visually recognize. In general, this threshold is one dot on the screen. Fig. 7 shows an example of the merging of two medical events in XML format.

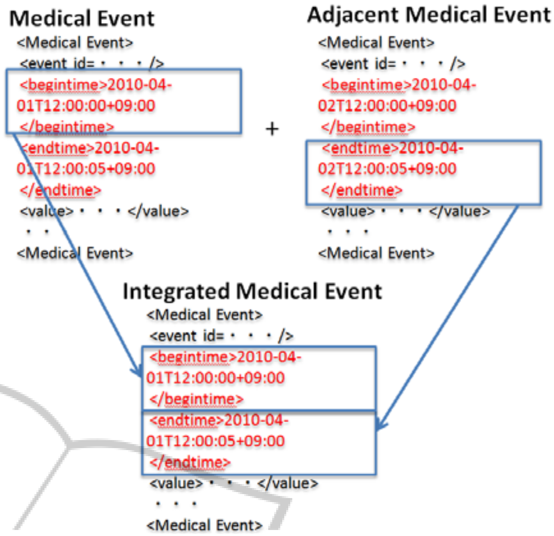

Figure 7: Event Merge in XML.

4. The system registers the data in each of the DB tables.

5. The system generates the chart using new data objects. Fig.8 shows how it looks like in the TimeLine interface.

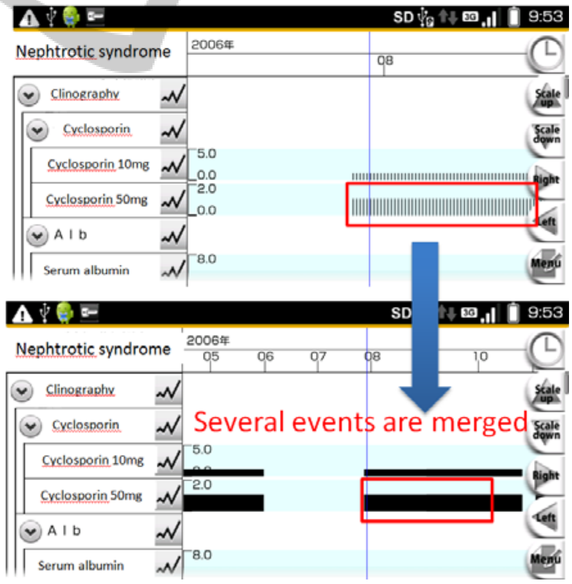

Figure 8: Adaptive Event Merge in TimeLine.

As can be seen, if the time scale changes, several events merge adaptively. In addition, to reduce the time required to draw the charts, we had the server draw the chart and transmit the image to the client device. In this manner, the system reduces data processing and improves responsiveness.

4 EXPERIMENTAL RESULT AND EVALUATION

To evaluate our system, we held a small-scale experiment in medicine. So in this section, we present the evaluation results obtained by physicians.

4.1 Experimental Conditions

First, the experimental conditions are introduced.

4.1.1 Evaluators

Fourteen physicians from six departments were chosen as evaluators (Table.1).

Table 1: Evaluators.

Department	Number of physicians
Pediatrics	7
Circulatory Medicine	1
General Internal Medicine	1
Respiratory Medicine	3
Fixed Prosthodontics	1
Dentistry	1
Total	**14**

A smartphone and PC was used as the system's client device and the system's server, respectively. The specifications are presented in Table.2.

Table 2: Specifications of the device.

	Client Mobile Device	Server PC
OS	Android	Windows 7 32-bit
CPU	Snapdragon 1 GHz	Intel Core i7-620UM 1.06 GHz
Memory	256 MB	4 GB

4.1.2 Form of the Questionnaire

All physicians answered a questionnaire designed to evaluate the system. For each question, there were five choices. A score of 5 represents the most positive answer. Conversely, a score of 1 was the most negative answer. Fig. 9 shows an example of the questionnaire we used.

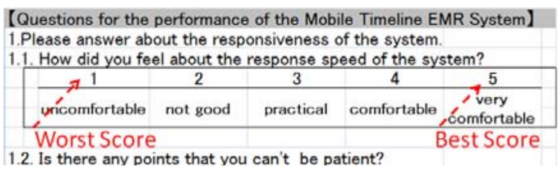

Figure 9: Example of the questionnaire.

4.1.3 Evaluation Items

The main evaluation items are listed below:

1. The situation in which physicians used the system:

We asked where the physician used the system for analyzing inpatients' and outpatients' medical data. This result corresponds to the TimeLine evaluation in our system.

2. The response speed of the system:

The response speed of the system is an important factor when determining the system's usability. This result corresponds to the *adaptive event merge algorithm* evaluation in our system.

4.2 Results

The experimental results for each evaluation item are presented in this section.

4.2.1 Location of Use

Fig.10 shows the evaluation result for the location where physicians analyzed outpatients' medical data. Each horizontal bar represents the evaluation scores for each answer listed on the left side. Also, average evaluation scores for each answer are shown on the right side of the bar. (Fourteen physicians, including a clinician from outside the hospital participated in the survey, so the answers "other rooms" and "ward" have 13 responses.)

Question: Do you want or need to use the system to analyze outpatients' medical data in these places?

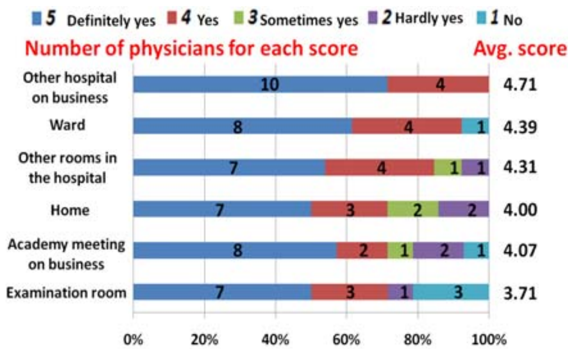

Figure 10: Evaluation result for outpatients.

Fig.11 shows the evaluation result for the places where inpatients' medical data are analyzed.

Question: Do you want or need to use the system to analyze inpatients' medical data in these places?

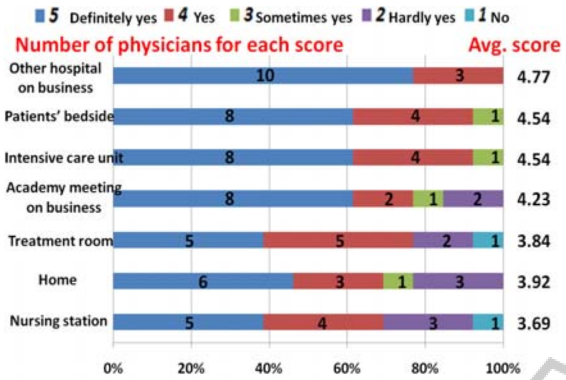

Figure 11: Evaluation result for inpatients.

As can be seen, there is a certain need to use our system anywhere. In particular, there is a remarkable need to use it at other hospitals, at the bedside of patients, and in intensive care units. These are the places where physicians cannot use conventional medical systems in spite of the fact that they need to refer to the patient's medical data.
Also, these physicians can be divided into two groups according to their department.

・Category1: Physicians who have to analyze the medical data over a long time span (e.g., pediatrics).
・Category2: Physicians who have to analyze the a patient's recent medical data for short time span (e.g., respiratory medicine).

According to these categories, evaluation results reveal weaknesses for the situations below:

・Situation 1 (usual working situation):
ward, examination room, other rooms, patient's bedside, intensive care unit, treatment room, nursing station
・Situation 2 (non-standard working situation):
working in other hospitals, academic meetings, at home

Table 3 shows the average evaluation score for each category.

Table 3: Average score for each category.

	Situation1	Situation2
Category1	4.41	3.91
Category2	3.67	4.73

These results indicate that physicians in category 1 have a greater need to use our system in usual rather than non-standard working situations. Conversely, physicians in category 2 have a greater need to use our system in non-standard working situations.

Physicians in Category 1 often need to analyze medical information covering a long time span in order to make a medical diagnosis. For example, the reference values differ depending on the patient's age, particularly children aged less than 20 years. Thus, pediatricians often need to analyze and compare medical history information when creating a medical treatment plan especially at a place where they see their patients without access to a conventional medical system, such as at the bedside. On the other hand, physicians in Category 2 often need to analyze medical information covering a short time span in an emergency. For example, if the condition of a patient suddenly changes, they have to make their decisions by accessing the contraindications for newly released medications especially where they cannot see the patient's medical history with a conventional medical system, such as outside the hospital.

4.2.2 System Response Time

In order to evaluate the performance of our system, in addition to the physician evaluations, in another experiment, we measured and compared the response time of our system with *adaptive event merge algorithm* and the system without it. In the experiment, the system randomly chooses the time span and draws a graph using medical records for the selected time span. Data used in the experiment are presented in Table.4.

Table 4: Number of medical events for typical patients case (Experimental data).

Patient	Number of medical events
Diabetic	2374
Nephrotic syndrome	7439
Dwarfism	8935

For each set of medical data, we repeated the experiment 54 times and measured the average time for drawing graphs using medical events from each patient's medical records. Table.5 shows the result.

Table 5: Averaged response time of proposal method (system with *adaptive event merge algorithm*) and conventional one (system without *adaptive event merge algorithm*).

Patient	Proposed	Conventional
Diabetic	75.3(ms)	1945.98(ms)
Nephrotic syndrome	82.3(ms)	2966.9(ms)
Dwarfism	116.9(ms)	3216.8(ms)

The result indicates that our proposed method was about 30 times as fast as the conventional method. Additionally, we conducted a subjective evaluation of our system's responsiveness. Table 6 shows the number of physicians who chose each score in response to the question "What was your impression of the responsiveness of our system?"

Table 6: Physicians' evaluation for responsiveness.

Score	Number of physicians
5 (excellent)	3
4 (good)	6
3 (acceptable)	4
2 (not good)	0
1 (poor)	1

As can be seen, at least 9 of 14 physicians evaluated the responsiveness of our system as acceptable. Thus it can be asserted that the responsiveness of our system is sufficient for clinical use.

5 CONCLUSIONS

In this paper, we presented a new medical system.

The system has the three features listed below:

1. The client application of our system works on mobile devices like a smartphone and can be used anywhere.
2. The client application has a timeline interface that visually displays the medical records of the patient.
3. Via the adaptive event merge algorithm, the client application responds quickly.

Due to these features, our system satisfies the physician's need to be able to make medical diagnoses regardless of where they are. Through the experiment that compared our system to the conventional method, we showed that our system using the adaptive event merge algorithm enables a response at least 30 times as fast as the conventional system. Also by conducting a qualitative evaluation, we showed that the performance of our system is acceptable for clinical use. Through the experiment and the analysis of the result, we showed that there are different usage patterns according to the specialty of the physicians.

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