A Pen-based Interface for Generating Graphical Reports of Findings in Cardiac Catheterization

Y. Mori[1], T. Igarashi[1], R. Haraguchi[2], K. Nakazawa[2]
[1]The University of Tokyo, Tokyo, Japan
[2]National Cardiovascular Center Research Institute, Osaka, Japan

Summary

Objectives: This paper introduces a pen-based interface for the graphical reporting of findings in cardiac catheterization.
Methods: The user can interactively draw, erase, move, and deform coronary arteries as well as record stenoses on them. The location and degree of each stenosis is represented visually and the doctor can record various treatments such as bypasses and stents on the diagram. In addition, the system automatically extracts semantic information from the graphical representation and stores it in XML format. The system can also generate a table in the format specified by the American Heart Association.
Results: Our current implementation is a research prototype and is not yet being used in clinical practice. However, we have already demonstrated it to medical professionals and confirmed the following benefits.
Conclusions: This system is useful not only as a tool for efficiently generating reports of findings but also as an effective explanation tool for patients.

Keywords

User-computer interface, medical records, heart catheterization, coronary arteries, coronary artery bypass, coronary stenosis

Methods Inf Med 2007; 46: 694–699

1. Introduction

Electronic medical recording systems [1-4] have become widespread due to the improvement in hardware performance and user interfaces. However, usability is still an issue and medical professionals need more such user-friendly interfaces. To make these systems accessible to inexperienced users and to reduce the overhead of data entry, we have been developing various pen-based electronic medical recording systems [5, 6]. Pen-based computing is an active research area for both user interfaces and computer graphics. Our work is based on recent advances in this area, especially the freeform user interfaces proposed by Igarashi [7]. Using this approach, the user draws freehand lines on the screen assisted by the system, and the result is directly stored as a vector image. Our systems feature special purpose functions for pen input including 3-D sketching, user-identification, and handwritten character recognition and search [6]. They are designed to help medical professionals to think more freely when working on difficult problems without being constrained by cumbersome interfaces.

One problem with these freeform pen-based systems, however, is that their output does not easily fit into a structure that lends itself to further machine processing or interface with other more traditional recording systems. Our goal in the project presented in this paper was to bridge this gap between freeform diagramming and more structured recording.

One strength of pen-based systems is that they make it easy to draw and add diagrams to medical records. This is particularly useful in ophthalmology, otolaryngology, and dentistry in which diagrams play an important role in medical records. Indeed, the frequent use of diagrams makes it difficult to use traditional GUI-based medical recording systems in these areas. Cardiac catheterization is one of these areas in which the diagram is an indispensable tool for medical recording. Existing electronic medical recording systems rely on structured templates, but it is difficult to create an appropriate report of findings or treatment plan using these predefined templates. Most existing diagram editors are implemented as bitmap paint tools, not vector graphics. This makes it difficult to edit the geometry afterward and requires a large amount of data to be transmitted and stored.

We therefore developed a pen-based interface for graphical reporting of findings in cardiac catheterization (Fig. 1). The user can freely "sketch" coronary arteries and stenoses on the screen using a pen on a template of coronary features. The location and degree of each stenosis, and various treatments such as bypass and stents, are visually represented. We developed an algorithm that can extract semantic information from the graphical representation and store it in XML format. The system can also generate a table in the format specified in the AHA (American Heart Association) committee report [9]. This system is useful not only as a tool for efficiently generating reports of findings but also as an effective explanation tool for patients.

2. User Interface

Figures 1 and 2 show screen snapshots of our system. The user can draw on the diagram template using a pen as if drawing on real paper. Our system shows the name of

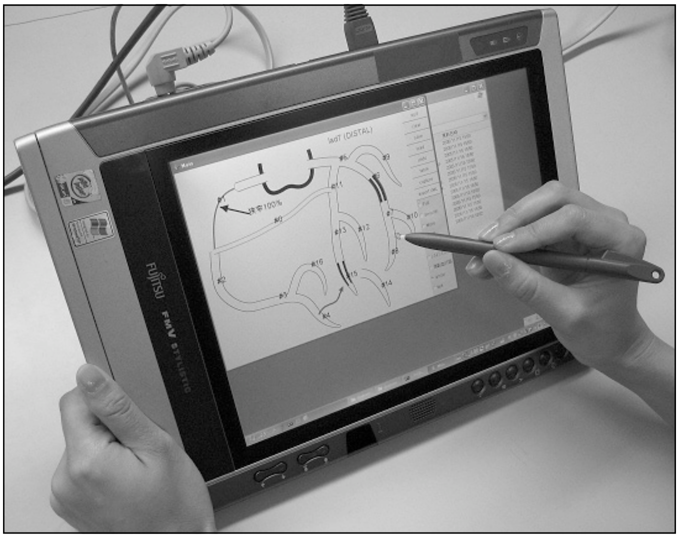

Fig. 1 A screenshot of our system in use

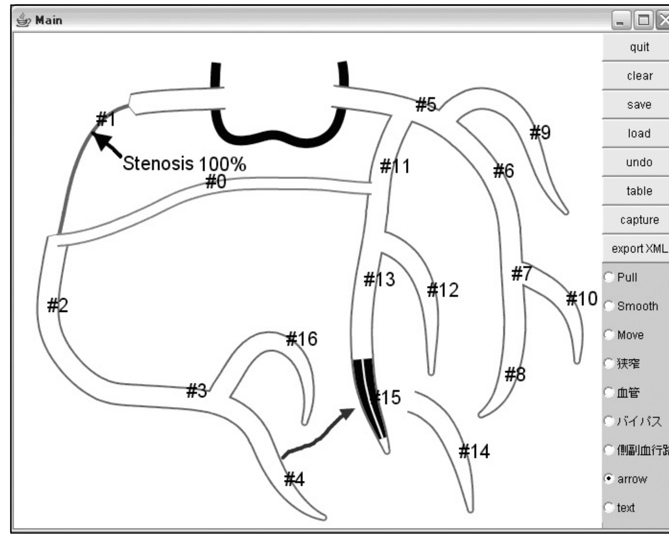

Fig. 2 Recording example of cardiac catheterization

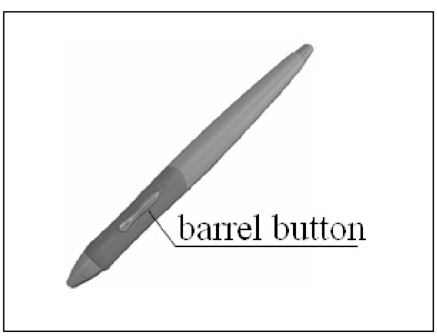

Fig. 3 Barrel button on pen

each coronary artery and segment (e.g., proximal, middle, or distal) at the upper right of the screen when the cursor is over any vessel. We use the naming scheme defined in the AHA committee report. The system can show borderlines of coronary artery segments if required.

Our system is a Windows application that provides a familiar interface to permit new users to work with it without extensive training. For example, the system displays a pop-up menu when the user clicks on a window while pressing the barrel button on the pen (Fig. 3). This section describes the user interaction steps one by one. The next section describes our algorithm.

2.1 Insertion/Editing of Vessel

Upon start-up, our system displays a default cardiac catheterization coronary schema. The user can then draw a finding report or a treatment plan on the schema. The system provides several functions for editing the geometry on screen, including adding, deleting, and deforming arteries.

The user can draw a new coronary artery with the pen after choosing the "draw coronary artery" mode from the tool palette on the right (Fig. 4a). The system automatically creates an appropriate junction where the new artery is connected to another, and tapers the free end. The user can delete a vessel by clicking on it while holding the barrel button down and choosing "delete" from a pop-up menu. The system automatically updates the display on the screen. The user can move an artery by dragging it with the pen after choosing the "move coronary artery" mode from the tool palette (Fig. 4b). The user can deform an artery by dragging it with the pen (Fig. 4c) after choosing the "pull coronary artery" mode from the tool palette. The system also provides a tool for smoothing coronary arteries, necessary when an artery drawn by hand is too jagged. To smooth an artery, the user simply rubs it with the pen (Fig. 4d). The user also can set the line width to large, normal, or small.

2.2 Recording of Stenoses

Once the user has sketched the geometry of the coronary arteries, he or she can record stenoses. To do this, the user chooses the "draw stenosis" mode from the tool palette and draws the stenosis on the target artery with the pen (Fig. 5a). When the user completes drawing and lifts the pen from the screen, the system displays a dialog box to specify the type and severity of the stenosis (Fig. 5b). If the user wants to change the properties of an existing stenosis, he or she can open the properties window by clicking on the affected artery while holding the barrel button down. The display of each stenosis on the screen includes the severity specified by the user (Fig. 5c).

The user can also move an existing stenosis by dragging it along the coronary artery (Fig. 6). The stenosis snaps to the border of the appropriate section of the artery as it moves.

If the severity of a stenosis is set to 100%, the portion of the artery beyond the stenosis is shown as a thin line (Fig. 7a) representing a complete blockage where no blood flows. The system automatically analyzes the tree structure of arteries and closes any downstream vessels as well.

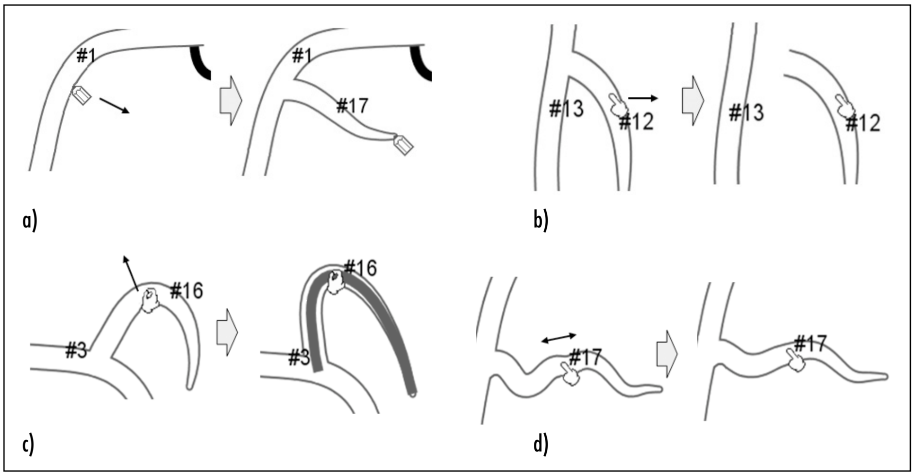

Fig. 4 Editing operation of a coronary artery. a) Draw a new coronary artery, b) move a coronary artery, c) pull a coronary artery, d) smooth a coronary artery

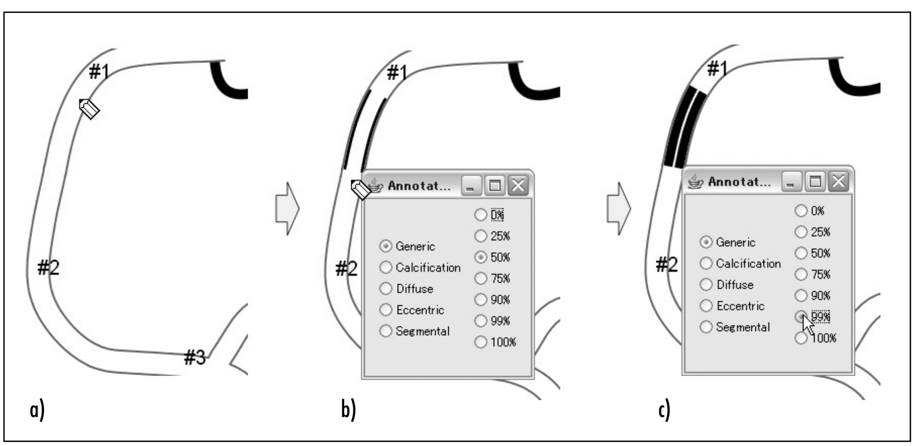

Fig. 5 Recording a stenosis

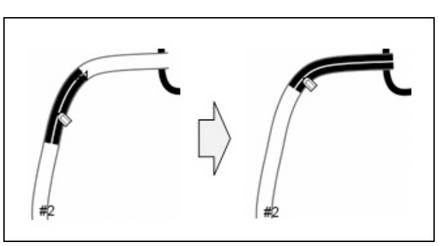

Fig. 6 The user can move an existing stenosis by dragging it along the coronary artery.

2.3 Bypasses and Collateral

The user can add a bypass to the schema by drawing a line connecting coronary arteries. If the bypass connects an open artery to a closed one, the system automatically opens the blockage to indicate that blood flow has been restored (Fig. 7b). The user can place a stenosis on a bypass just like on a coronary artery and can also delete, move, and pull a bypass.

The user can draw a collateral (new blood vessels that reroute blood flow around a stenosis) by drawing a line between coronary arteries. This appears as an arrow in the schema (Fig. 8). Our current implementation does not modify the blood flow automatically in response to a new collateral.

2.4 Stent

The user can place a stent in a coronary artery (Fig. 9). Recording of stents is very important for documenting the treatment of the stenosis. The procedure for editing a stent is identical to that for editing a stenosis. The user creates and moves a stent by dragging it along a coronary artery and deletes it using a pop-up menu. The stent also snaps to the borders of the artery segments.

2.5 Other Functions

The user can annotate the schema as a record of miscellaneous medical diagnosis and treatment. Our current implementation supports text and arrow marks in annotations (Fig. 10). Unconstrained annotation encourages the user to think freely, similar to handwriting notes on traditional paper medical records. It is also helpful to remind the user of miscellaneous details associated with specific treatments.

The system can save an edited coronary schema, and then load it again for review or further editing. The schema is stored as vector graphics to reduce file size and facilitate editing. The system can export a schema in PNG image format for import into another system.

The user can create a new schema starting from a default coronary schema template and can also specify any schema to be the default template.

3. Dataset Structure and Co-operation with Other Systems

Many doctors use coronary angiography (CAG) to represent coronary stenosis pathology. CAG compactly shows the location and severity of stenoses. Our system supports the conversion of the graphical record to a CAG-compliant table dataset. The table is represented in the format specified in the AHA committee report and stored as an XML file. Figure 11 shows the relationship between our system and CAG. The top screen in Figure 11a presents an example of recording stenoses using our system; the middle screen of Figure 11a shows the CAG dataset it produces. Any other system that supports this format can use the data file as shown in the bottom screen of Figure 11a.

The user can also edit the exported CAG table. When this happens, our system automatically updates the corresponding stenosis on the coronary diagram including the information on the severity and character of the stenosis (Fig. 11b).

4. Implementation

We designed our system as a platform-independent Java™ program using the Java2D™ graphics application programming interface. This section describes the implementation details of the current prototype.

4.1 On-screen Display

The system displays coronary arteries as two parallel lines and handles the branches appropriately (Fig. 2). A vessel is a polyline composed of small line segments. The system first draws a wide red line and then a narrow white line inside. The width of these lines decreases toward the non-connected end of a vessel to represent the taper.

A stenosis is displayed in a similar manner. The system first draws a wide black line inside the vessel and then a narrow white line inside that. A stent is rendered by drawing a hatching pattern after setting a stencil inside the stent area.

4.2 Geometry Editing

The pulling interface deforms the curve while maintaining its local details (Fig. 4c) [10]. The system first generates triangles by connecting sets of three neighboring points on a polyline. As the user pulls a point along the curve, the system determines the location of free vertices so as to minimize the distortion of the triangles. We also used the peeling interface introduced in [10] to adjust the size of the region to be deformed, so that a larger area is deformed as the user pulls more.

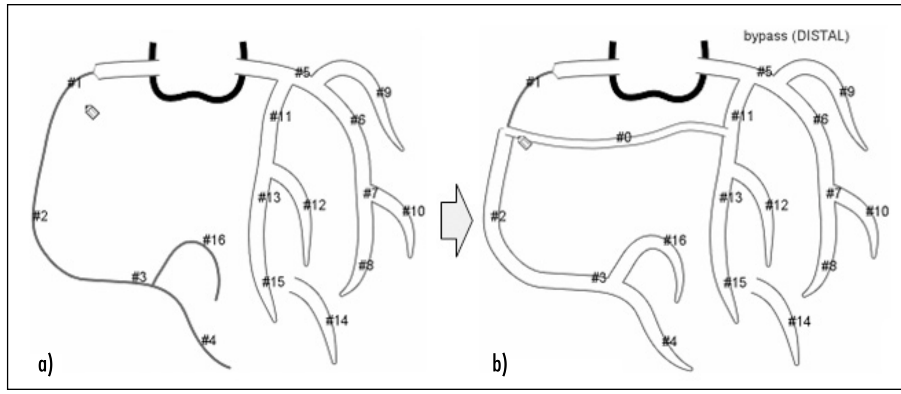

Fig. 7 Drawing a bypass. If the bypass connects an open coronary artery to a closed one (a), the system automatically opens the closed coronary artery to indicate that blood flow has resumed (b).

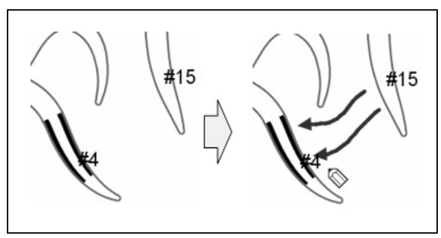

Fig. 8 Example of recording a collateral

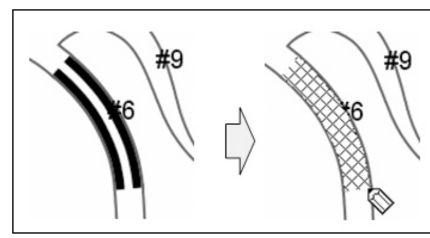

Fig. 9 Example of placing a stent

4.3 Smoothing

The smoothing tool reduces the jagged edges along a curve caused by unsteady hand movement during drawing. As the user moves the cursor back and forth, the system moves the nearest vertex along the curve so that the curvature at the vertex becomes the average of the curvatures at the neighboring vertices (Fig. 4d).

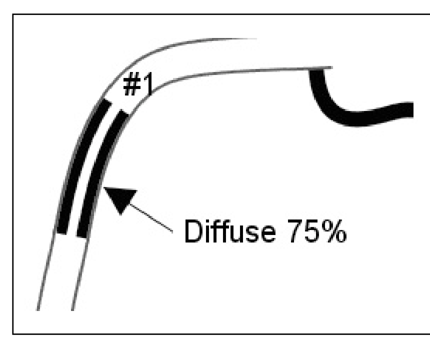

Fig. 10 Example of recording text and arrow marks as annotation

4.4 Generating the CAG Table

The CAG table stores the following information for each segment of a coronary artery: the presence or absence of a stenosis, the severity of the stenosis, and the type of stenosis (Fig. 11a, bottom). The system automatically generates a CAG table from a graphical coronary schema by checking for the existence of a stenosis in each segment. It stores the result in XML format (Fig. 11a, middle and bottom).

When the user edits the CAG table, the system first finds the corresponding stenosis in the XML file (Fig. 11b, top and middle). It then obtains the information for that stenosis and changes it on the coronary schema. In this way, the system automatically updates the stenoses on the coronary schema from the corresponding CAG table (Fig. 11b, bottom).

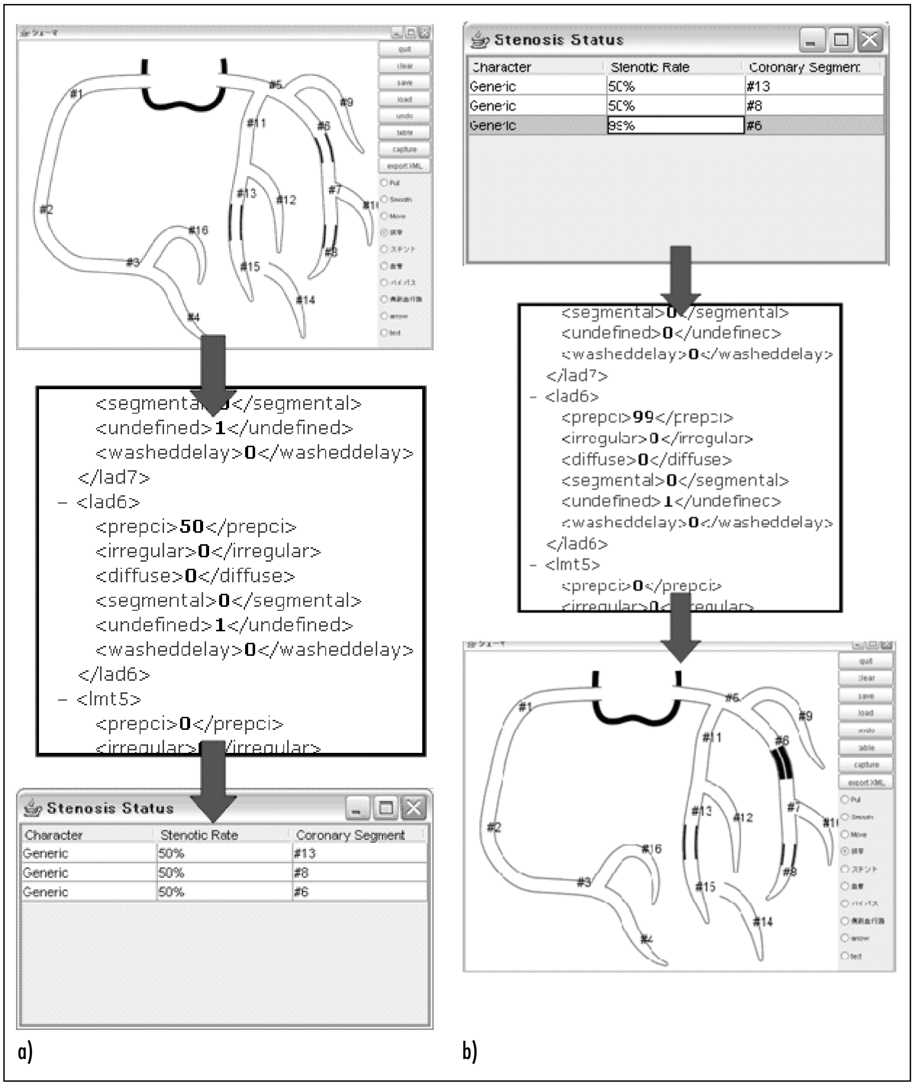

Fig. 11 Example of the automatic relationship between the coronary diagram and the CAG table. a) The system automatically generates a CAG table from a graphical coronary schema by checking the existence of a stenosis in each segment of the coronary arteries and stores the result in XML format. b) The system can automatically update the stenoses on the coronary schema from the corresponding CAG table.

5. Discussion

Our current implementation is a research prototype and is not yet being used in clinical practice. However, we have already demonstrated it to medical professionals and confirmed the following benefits:

1) The user can easily modify the geometry of coronary arteries for individual patients.
2) The system can store the data compactly using vectors instead of bitmaps, which significantly improves the network response when storing information on a remote server.
3) The system can export the CAG table based on the AHA committee report in XML format. Therefore, the system can easily exchange data with other existing systems.
4) The user can edit a coronary schema while viewing a reference image on the same display.
5) The user can draw diagrams and text freely in our system, which allows the recording of new anomalies that have never been previously observed.

An issue with the current implementation is that it is limited by the AHA standards. The manner of recording schemas for cardiac catheterization varies widely among users and facilities. As the AHA committee report was designed more than 30 years ago, it cannot handle many cases well. Therefore, a more powerful and flexible representation is needed.

6. Conclusion and Future Work

We developed an effective interface for reporting graphical findings in cardiac catheterization using hand-drawn diagrams. The user can easily record the position and degree of a stenosis on a coronary schema template, and can also record treatments such as bypasses and stents. Once a bypass is added, the system automatically displays the resumption of blood flow. This type of automatic adaptation is not possible with paper-based medical records. Our system can store the data as a CAG table in an XML file in the AHA format for exchanging data with other existing systems. Our system makes it easier to handle graphical schemas in medical recording systems, encouraging the spread of medical recording systems in general.

Our system operates independently and does not require any other special infrastructure. Therefore, it can be easily introduced at low cost. We hope to put our system into actual clinical practice to make improvements based on feedback from actual users. We also plan to experiment with 3-D schemas because 3-D images are becoming increasingly widespread.

The interactive graphical schemas introduced in this paper should be useful in not only cardiac catheterization but also other areas that use schemas, for example, ophthalmology, otolaryngology, and dentistry. Such interactive schemas are useful not only for efficiently generating finding reports but also as an effective explanation tool for patients.

References

1. Matsumura T. Electronic Medical Record and Hospital Information System: Comprehensive Management of Patient Information. Japan Journal of Medical Informatics 2001; 21 (3): 211-222 (in Japanese).
2. Matsumura Y. Current Status of Electronic Medical Record and its Tasks. Medical Frontline 2003; 58 (8): 46-51 (in Japanese).
3. Sitting DF, Kuperman GJ, Fiskio J. Evaluating Physician Satisfaction Regarding User Interactions with an Electronic Medical Record System. Proceedings of the AMIA Annual Symposium 1999, 99: 400-404.
4. Ginsburg M. Pediatric Electronic Health Record Interface Design: The PedOne System. Proceedings of the 40th Hawaii International Conference on System Sciences 2007. p 139.
5. Nakazawa K, Igarashi T. A Comprehensive Computer Interface for the Spreading of Electronic Medical Recording Systems Supporting Handwriting Inputs by Pen Device. New Medicine in Japan 2003; 345: 74-77 (in Japanese).
6. Nakazawa K, Haraguchi R, Yao T, Nagata S, Sugimoto Y, Ashihara T, Takada M, Namikawa H, Okada Y, Yoshimoto K, Furuya N, Senda S, Uematsu Y, Igarashi T. Pen-based Interface for Electronic Medical Record System with Advanced Recognition and Search Engine for the Hand-written Characters. Japan Journal of Medical Informatics 2005; 25 (2): 81-86 (in Japanese).
7. Igarashi T. Freeform User Interfaces for Graphical Computing. Proceedings of the 3rd International Symposium on Smart Graphics, Lecture Notes in Computer Science. Heidelberg, Germany: Springer; July 2-4, 2003. pp 39-48.
8. Sakabe N, Arai K, Abe K, Inoue H, Sakai S, Watanabe Y. A Survey of Demerits of Electronic Medical Record in the Ear, Nose and Throat Department. Japan Journal of Medical Informatics 2001; 21 (1): 131-136 (in Japanese).
9. Austen WG, Edwards JE, Frye RL, Gensini GG, Gott VL, Griffith LS, McGoon DC, Murphy ML, Roe BB. A Reporting System on Patients Evaluated for Coronary Artery Disease. Circulation 1975; 51 (Suppl. 4): 5-40.
10. Igarashi T, Moscovich T, Hughes JF. As-Rigid-as-Possible Shape Manipulation. ACM Transactions on Computer Graphics 2005; 24 (3): 1134-1141.

Correspondence to:
Yuki Mori
H. Suzuki Lab. Research Center for
Advanced Science and Technology
The University of Tokyo
Room #303, RCAST Building #4
Komaba 4-6-1, Meguro
Tokyo153-8904
Japan
E-mail: yukim@acm.org