Interactive Dental Care Interface (IDCI)

Tuan Anh Vo
Dept. of Elec. and Comp. Engineering
University of British Columbia
2366 Main Mall
Vancouver, B.C V6T 1Z4
1-604-827-4059
vo@interchange.ubc.ca

ABSTRACT
It is difficult for a dental patient to speak to the dentist during a dental operation because the patient’s mouth is often required to be opened throughout the operation. In this paper, we present IDCI (Interactive Dental Care Interface) which is an interactive interface that allows a patient to communicate with the dentist during a dental operation. The interface allows the patient to use a touch pad to select messages from the user interface to be sent to the dentist. The interface also allows the patient to use the grip sensor to send the hand’s gripping pressure, which expresses the patient’s pain level due to pain withdrawal reflex, to the dentist. The dentist uses this information to take actions accordingly. The user study shows that IDCI is easy to use and is effective in helping the patient to communicate messages and pain to the dentist.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces – auditory feedback, graphical user interfaces, input devices and strategies, screen design.

General Terms
Measurement, Experimentation, Human Factors, Languages, Design.

Keywords
User interface, augmentative communication, pain feedback

1. INTRODUCTION
It is often desirable for the patient and dentist to communicate with each other during a dental care session. For example, the patient might want to inform the dentist that he or she is in deep pain so that the dentist can take actions accordingly; the dentist might want to know whether the patient is feeling pain at a particular spot inside the mouth; the patient might want to tell the dentist to suck up the fluid in his or her mouth.

However, the patient’s mouth is usually required to be anchored open throughout most of the dental session, and therefore, the patient can not speak to the dentist during the operation. To resolve this issue, augmentative communication, which are non-verbal techniques used to augment a person’s oral speech, is necessary to overcome the difficulty. [8]

This paper introduces the interactive dental care interface (IDCI) that allows the patient to communicate common messages and pain to the dentist. With IDCI, the patient can use a touch pad device to select and output common messages to the dentist through a display and audio. In addition to the touch pad, the patient can use a grip sensor to communicate pain to the dentist. IDCI uses this grip sensor to detect the gripping pressure of the patient’s hand and translates the pressure signal into a pain representation feedback, using a display and audio, to notify the dentist. Base on the pain feedback, the dentist could react correspondingly in real-time. Pain is one of the reasons why people hesitate to go the dentist. [11] The pain feedback mechanism allows the patient to inform the dentist of the pain level, and therefore, the patient will feel more comfortable going to see the dentist.

2. MOTIVATION
At present, the dentist relies on the patient’s limited gestures to determine what the patient is trying to communicate during a dental session. For example, if the patient is in pain, the patient’s face and body would tense up. The patient can answer a yes or no question by nodding or turning his or her head. There is no good way for the patient to remind the dentist to suck up the fluid in the patient’s mouth. The dentist would have to visually check the mouth’s movements or the amount of fluid in the mouth.

There are things that the patient cannot communicate to the dentist without speech. For example, the patient cannot ask the dentist how much longer the operation will take; the patient cannot tell the dentist that his or her last check up is two years ago; the patient cannot tell the dentist to clean the patient’s face.

There are various software programs designed to implement many forms of speechless communication. These programs cost in the range of one hundred Canadian dollars to one thousand Canadian dollars, with the more expensive ones consisting of more features. For example, Writing with Symbols 2000 is a word and picture processing program that allows you to type words and have them display as picture symbols on screen. The program also allows you to select picture symbols on the screen to produce words. These words can be read out loud by the program. This is one of
the cheaper programs out there costing only two hundred dollars. One of the more expensive programs is the Grid 2 which costs about nine hundred dollars. The Grid 2 program allows the use of a computer as a voice output communication aid, using symbols or text to build sentences. This program supports the core features of Writing with Symbols 2000 plus more. Typically, the first screen consists of a number of topics. Selecting a topic leads to a grid with vocabulary specific to that topic. As you type, Grid 2 can suggest the words that you are typing. The Grid 2's advanced prediction system learns as you write, so words that you use regularly are given higher priority.

However, these programs are not suitable for use during a dental operation. They require a long learning curve and a lot of interaction with the user interface to create a message. Our research shows that there is no communication system available that is designed specifically for assisting the patient in communicating with the dentist during a dental operation.

3. REQUIREMENTS & DESIGN

3.1 Requirements

The focus of IDCI is to provide an interface that is simple for the patient to use and learn, and requires minimal patient’s interaction. These requirements are desirable in a dental office setting where the patient is lying down and the patient is often in pain. Only the patient can interact with the interface. The IDCI system should accommodate left-handed and right-handed patients. Also, the IDCI system should not get in the way of the dentist so that the dentist can perform his or her work as normal.

3.2 High Level Design

The high level design of IDCI is shown in Figure 1. The dentist’s LCD display is mounted behind the dental chair, and it is facing the dentist during the operation. The patient’s LCD display is mounted above the dental chair, and it is facing toward the patient. The touch pad and grip sensor are mounted on the arm rests of the dental chair. Both the touch pad and grip sensor can be detached and mounted on either side of the dental chair base on the patient’s preference. We have chosen to use a touch pad instead of a mouse or joystick because the touch pad can easily be used at an angle. The touch pad can be rotated perpendicular to the patient’s arm to suit the patient’s preference. During the operation, the patient can squeeze the grip sensor to notify the dentist of his or her pain level. This squeezing action can be caused by the pain withdrawal reflex as described in [9][10] or subjectively actuated by the user to express his or her pain to the dentist.

3.3 Detailed Design

The detailed design of IDCI is shown in Figure 2. Data is flowed from top to bottom. The patient provides inputs to the IDCI system through either the touch pad or the grip sensor. The touch pad takes movement and click inputs from the patient and sends that information electronically to the IDCI system. The grip sensor consists of the pipet, pressure sensor and phidget. When the patient grips the pipet, the pressure sensor detects the air pressure inside the pipet and sends that information to the phidget. The phidget then sends that information electronically to the IDCI system through either the touch pad or the grip sensor.
The IDCI system takes inputs from the grip sensor and touch pad, performs actions, and displays the same information on both patient’s and dentist’s LCD displays. The IDCI system outputs audio sound when the grip sensor signal input indicates that the patient is in pain. The IDCI system also outputs synthesized speech whenever the patient selects a message on the user interface. The speech represents the message that the patient would like to tell the dentist.

4. IMPLEMENTATION

4.1 Hardware

IDCI consists of a pipet, pressure sensor, phidget, touch pad, patient’s LCD, dentist’s LCD, computer (IDCI System) and speakers (see Figure 2). The end of the pipet is fed into the pressure sensor which is connected directly to the phidget. The output of the phidget goes to the computer. The computer is the heart of IDCI, and it uses the WindowXP operating system. The touch pad, two LCD displays, and speakers are connected directly to the computer.

4.2 User Interface

![User Interface](image)

The user interface of IDCI is simple and easy to use. It consists of buttons that the patient can interact with and a meter indicator to show the patient’s pain level (see Figure 3). The interface consists of brown buttons at the border of the screen. These buttons have icons and text to describe the messages that the patient would like to inform the dentist. When each of these buttons is selected, the button will be highlighted and its detailed description will be shown in the middle of the screen. A synthesized speech sound will also be played when a button is selected. The speech sound reads the detailed button’s description in the middle of the screen. The right side of the interface has a pain meter. A fully red meter indicates that the patient is in extreme pain, and an empty meter indicates that the patient is not in pain. The plus and minus buttons below the pain meter allow the patient to change the number on the right of the plus button. The number can be an answer to the dentist’s question such as “how many months ago was your last check up?”.

4.3 Interface Design Rule

According to Fitts law, the button size and distance determines the time of navigation as shown in the following relationship:

\[ T = \log_2 \left( \frac{D}{W} + 1 \right) \]

with T equals to the time for a selection, D is the distance traveled to make the selection and W is the size (width and height) of the button control. [7]

To minimize T, we use big buttons and placed the buttons close to each other along the border. By placing the buttons along the border, the buttons’ sizes become infinite (imagine the button can extend beyond the border) and therefore, they reduce the selection time T.

4.4 Pain Sensing

As described earlier, the pressure sensor provides the pressure values to the system. The system samples the pressure values at 30Hz using a software timer. After each sampling, the pressure values are mapped to pain feedback values in the range of 1 to 100 using a predefined mapping function. Two mapping functions were designed and implemented:

1. Linear mapping function:

   \[ \text{PainFeedbackValue} = a \times \text{PressureValue} + b \]

   where \( a \) and \( b \) are the function coefficients used to calculate the pain feedback values.

2. Inverted parabolic mapping function:

   \[ \text{PainFeedbackValue} = a \times \sqrt{\text{PressureValue} + b} \]

   where \( a \) and \( b \) are the function coefficients used to calculate the pain feedback values.

Using these pain feedback values and 3 thresholds (set at 25, 50 and 75), the pain feedback values can be divided to represent 4 different levels of pain. No pain is in the range of 1 to 25; low pain is in the range of 26 to 50; medium pain is in the range of 51 to 75; and high pain is in the range of 76 to 100.

To ensure the proper mapping for various users, a calibration routine was implemented to tune the function’s coefficients. This is a self calibrating process. It is designed so that the user is required to squeeze the grip sensor firmly for 5 seconds during the calibration. The process records the maximum and minimum pressure values actuated by the user and calculates the fitting function coefficients.

4.5 Audio Feedback

Other than visually showing the level of pain through the pain meter, there is also the audio feedback provided by the system. The audio feedback is implemented to generate a computer beep sound at 3 different frequencies, with each frequency corresponds to one level of pain. In addition, the number of beep generated varies according to the level of pain. At low level of pain, there is
a single beep; at medium level of pain, there are 2 beeps; at high level of pain, there are 3 beeps; at no pain, there is no beep.

The audio feedback is generated periodically and whenever the pain level changes. A simple low pass filter is used to avoid beeping during transients of the pain level changes.

5. PERFORMANCE MEASURE
There are two main performance measurements:

1. The effectiveness of the communication interface for patients who are unable to communicate verbally.
2. The effectiveness of expressing the patient’s pain through the pain sensing mechanism.

5.1 Participants
9 volunteers (5 females and 4 males) ranging from 24 to 65 years old participated in the performance measure experimentation. Although all participants have used the computer before, their computer experiences vary from 1 year to 12 years.

5.2 Hypotheses
Four hypotheses are used to measure the system performance as mentioned in the previous section:

1. The navigation and button selection time of the user interface of the system is within acceptable level for the users.
2. The icons on the user interface are intuitive for the users.
3. The learning period of the system is short for users in all categories.
4. The pain sensing mechanism reflects the pain feedback from the users properly.

5.3 Test Procedures
There were two test procedures. The first test procedure was used to validate hypotheses 1, 2 and 3, and the second test procedure was used to validate hypothesis 4.

The first test procedure is as follow:

1. The volunteer was asked 5 questions verbally, and the volunteer can answer verbally using one of the 8 answers written on a piece of paper: “Yes”, “No”, “Stop”, “Clean my face”, “Suck the fluid”, “How much longer?”, “What’s next?” and “I am in pain”. These answers were taken from the buttons of the user interface (see Figure 3). The volunteer’s responses were recorded. The time it took for the volunteer to response, after listening to the question, was recorded.
2. The volunteer was asked to answer the same questions as in Step 1 in random orders, and they were required to answer them on the user interface prototype with only iconic buttons (no descriptive text). No verbal responses were allowed. The time it took for the volunteer to response, after listening to the question, was recorded.
3. The volunteer was asked to answer the same questions as in Step 1 in random orders, and they were required to answer them on the user interface prototype with descriptive text on the buttons (no icons on buttons). No verbal responses were allowed. The time it took for the volunteer to response, after listening to the question, was recorded.

4. The volunteer was asked to answer the same questions as in Step 1 in random orders, and they were required to answer them on the user interface prototype with descriptive text on iconic buttons. No verbal responses were allowed. The time it took for the volunteer to response, after listening to the question, was recorded.

5. The volunteer was asked to answer another 10 questions which are different from those questions in Step 1. They were required to answer them verbally and on the user interface with descriptive text on iconic buttons. The volunteer’s responses were recorded. The time it took for the volunteer to response, after listening to the question, was recorded.

Due to ethical reason, performance measure of the pain sensing mechanism of the system was evaluated using an alternative method other than inducing pain to the volunteers. The volunteers were told to squeeze the grip sensor with different hand pressures according to the size and color of the circles displayed on a computer monitor. For instance, the volunteers should squeeze hard when they saw the biggest circle (red), which simulates the input action for high pain; volunteers should squeeze firmly for the second biggest circle (light red), which simulates the input action for medium pain; volunteers should squeeze slightly for the third biggest circle (white), which simulates the input action for low pain; and, the volunteers should not squeeze at all for the smallest circle (black dot), which simulates the input action for no pain.

The second test procedure is as follow:

1. The system was set to calibration mode.
2. The volunteer was asked to perform a calibration on the grip sensor by squeezing hard on the grip sensor for 5 seconds.
3. The volunteer was asked to look at the computer display screen, on which four different sized and colored circles were shown. The squeezing instructions, such as to squeeze hard for the biggest circle and not to squeeze for the smallest circle, were explained to him or her.
4. The system was set to testing mode and began with the linear mapping method of pain sensing.
5. The system randomly generated 5 different circles, and, for each circle, the volunteer should squeeze the grip sensor corresponding to the circle’s size and color. The size and color of the circles, the immediate audio feedback signals, and the corresponding visual display of the pain meter were all recorded.
6. The system was switched to use the inverted parabolic mapping method of pain sensing.
7. The same test as in step 5 was performed again, and the results were also recorded.

At the end of the two test procedures, each volunteer was asked to fill out a questionnaire as a subjective review of the system.

6. RESULTS AND ANALYSIS
After conducting the test procedures described in section 5, various response time data and accuracy data were collected. Table 1 summarizes the response time results obtained from the
first test procedure. The first column of the table shows the average and standard deviation of the response times of the volunteers when they answered the questions verbally. The second, third, and forth columns are the average and standard deviation of the response times of the volunteers when they used the icon only interface, the text only interface, and the text and icon interface, respectively. The last column is the average and standard deviation of the response times of the volunteers when they answered the 10 questions which were different from those 5 questions used in the previous test cases.

Table 1. Summary of response times of the test cases in the first test procedure

<table>
<thead>
<tr>
<th></th>
<th>Verbal Response</th>
<th>Icon Only</th>
<th>Text Only</th>
<th>Text &amp; Icon</th>
<th>Text &amp; Icon (10 qs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (Seconds)</td>
<td>2.17</td>
<td>6.82</td>
<td>2.06</td>
<td>1.47</td>
<td>1.04</td>
</tr>
<tr>
<td>Standard Deviation (Seconds)</td>
<td>1.28</td>
<td>6.45</td>
<td>1.26</td>
<td>0.63</td>
<td>0.46</td>
</tr>
</tbody>
</table>

As mentioned in the first test procedure, the verbal responses of the patient were recorded. These responses are used to determine the accuracy of the responses from step 2 to 5 of the first test procedure. Table 2 summarizes the accuracy results obtained during the first test procedure. The first, second and third columns are the average and standard deviation of the responses' accuracy with respect to the verbal responses of the volunteers when they used the icon only interface, the text only interface and the text and icon interface, respectively. The last column is the average and the standard deviation of the responses' accuracy of the volunteers when they answered the 10 questions which were different from those 5 questions used in the previous test cases.

Table 2. Summary of accuracy of the test cases in the first test procedure

<table>
<thead>
<tr>
<th></th>
<th>Icon Only</th>
<th>Text Only</th>
<th>Text &amp; Icon</th>
<th>Text &amp; Icon (10 qs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>69%</td>
<td>93%</td>
<td>98%</td>
<td>98%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>20%</td>
<td>10%</td>
<td>7%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Figure 4 depicts the average response time that each volunteer had taken during the testing. The data are plotted following the sequential order of when each test case was conducted. An apparent convergence trend can be seen from left (icon only test case) to right (text and icon test case).

Base on the response time data, the first hypothesis about navigation and button selection time can be validated. The response times in the verbal test case included the thinking time of the volunteers. Since the same set of questions was used on the rest of the test cases involving the use of the interface, the response times of the text and icon test case should be slightly adjusted. Let’s make an assumption that the volunteers’ thinking time is 1 second on average. The average response time of using the text and icon interface after the adjustment is 2.47 seconds (1+1.47), which is still comparable to the verbal response time of 2.17 seconds (see Table 1).

As suggested by the response time and accuracy data, the most accurate responses were collected when the volunteers were using the text and icon interface. The icon only interface got the longest response time out of all the test cases and the worst accuracy. Figure 5 shows the survey results of the questions on whether the icons on the interface are intuitive. 67% of the volunteers voted it to be fair, and 22% of the volunteers voted it to be poor. Therefore, the second hypothesis is considered to be invalid. In other words, the icons did not do a good job of helping the volunteers to select a response.

The third hypothesis about short learning period can be validated by comparing the response times of the test case using the text and icon interface to response to the first 5 questions and the test case using the text and icon interface to response to the last 10 questions. The average response time has been reduced from 1.47 seconds to 1.04 seconds, which is a 29% improvement. Accuracy
is maintained at 98% in both test cases. The improvement on the response times shows that the volunteers had adopted the interface and could use it quickly to respond to the questions.

The fourth hypothesis, using the pain sensing mechanism to properly represent the users’ pain feedback, can be validated by comparing the matching accuracy between the circles shown on the display to the volunteers and the recorded audio feedback signals and visual display of the pain level during the second test procedure. Table 3 summarizes the accuracy information collected.

<table>
<thead>
<tr>
<th>Table 3. Summary of the accuracy of using the pain sensing mechanism with two different mapping methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Volunteer 1</td>
</tr>
<tr>
<td>Volunteer 2</td>
</tr>
<tr>
<td>Volunteer 3</td>
</tr>
<tr>
<td>Volunteer 4</td>
</tr>
<tr>
<td>Volunteer 5</td>
</tr>
<tr>
<td>Volunteer 6</td>
</tr>
<tr>
<td>Volunteer 7</td>
</tr>
<tr>
<td>Volunteer 8</td>
</tr>
<tr>
<td>Volunteer 9</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>Standard deviation</td>
</tr>
</tbody>
</table>

When the pain sensing mechanism was using the inverted parabolic mapping method, it produced an 80% accuracy on average. Therefore, hypothesis 4 is validated, and the inverted parabolic mapping should be used instead of the linear mapping.

7. CONCLUSION
After conducting the experiments described in the previous sections, 3 of the 4 hypotheses are validated:
1. The navigation and button selection time of the user interface of the system is within acceptable level for the users.
2. The learning period of the system is short for users in all categories.
3. The pain sensing mechanism reflects the pain feedback from the users properly.

The invalid hypothesis is the intuitiveness of the icons on the user interface. The icons could be more representative of the messages, and this could be part of the future work of the project.

In addition, Figure 6 and Figure 7 show the subjects’ responses on ease of use of the user interface and grip sensor. The general responses are supporting the ease of use of the system from the volunteers. 7 out of 9 volunteers would like to use the system in their next dental care session, which further proves the acceptance of the system.

7.1 User Training
Although it was proven that the learning period of the system is very short, some preliminary user training would be helpful to assist the users to pick up the system even more quickly. For example, prior to the dental care session, a brief introduction of the buttons selection on the interface given by the dentist assistance could reduce the need to explore the interface by the users alone.

7.2 Pain Sensing
As mentioned earlier, due to ethical reason, actual pain feedback from the users cannot be obtained. In order to investigate the actual validity of the pain sensing mechanism, the system should be tested at a dental clinic and validated by real dental patients in the future.

7.3 IDC1 as Pain Relief Tool
Two general approaches are adopted by patients to handle pain. For the first approach, the patient attempts a solution aimed at pain relief, known as assimilation. For the second approach, the patient adopts a solution aimed at acceptance, known as accommodation. These two approaches are orthogonal. As investigated by [2], acute pain patients, such as dental patients,
tend to take the first approach to deal with their pain. Although IDCI is not a medication as in [5], the pain sensing pump can be considered as an alternative type of pain relief tool, similar to the stress relief ball available in the market and the research conducted in [7]. By squeezing the pump, the patient can potentially relieve his or her pain feeling. Future study can be conducted to investigate this aspect of functionality.

8. ACKNOWLEDGMENTS
Thanks to Dr. Sidney Fels for guidance in designing IDCI. Special thanks go to all the volunteers who participated in the testing process.

9. REFERENCES