Detection of Cerebrovascular Disease with Mobile Application

Abstract

**Background:** The prevalence of cerebrovascular disease has gradually increased to become the second leading cause of death in the world. Magnetic resonance angiography (MRA) evaluates the intracranial vessels without requiring invasive procedures.

**Object:** This study provides a novel anatomy cerebrovascular disease detection platform for mobile devices with Android systems that could be applied in the treatment of cerebrovascular disease, medical prevention, and health care.

**Method:** The system proposed herein can transfer information of a text, DICOM images, and the 3D cerebrovascular model from the server to the client. The platform design structure can be divided into five layers. The platform server was based on an event-driven mechanism and used an HTTP protocol to achieve faster and more effective data transmission. In addition, the client used a Model View Controller (MVC) model for platform development.

**Results:** This study investigated the reliability and effectiveness of the platform and examined user-related questions. Forty students who represented common users and 21 doctors who represented professional users participated in the experiment. The results indicated that both common and professional users were satisfied with the platform usage.

**Conclusions:** The experimental results implied that the platform could be a useful tool for detecting cerebrovascular disease and that it could be integrated into existing diagnosis methods and treatments. Furthermore, the platform could be extended to the detection of other diseases such as respiratory and cardiovascular diseases.

**Trial Registration:** ChiCTR-OCH-12002508

**Keywords:** Applications in subject areas; E-Health; health care; cerebrovascular disease; Android; message transfer
Introduction

Cerebrovascular disease is the number one threat to people’s health. Around the world, more than 15 million people die from this disease annually[1]. Cerebrovascular disease has characteristics such as high morbidity, high disability rate, high mortality, and high recurrence rate; moreover, it is very common in people aged over 50 years. China is the most heavily populated country in the world, and thus, if we only depend on the traditional treatment processes to prevent and diagnose cerebrovascular disease, it would cause heavy burdens on hospitals and increase the difficulties faced by patients to get treatment in time. Nowadays, medical technology is developing quickly, and imaging technologies aimed at treatment of cerebrovascular disease such as computed tomography angiography(CTA) can obtain high precision with competitive cost. These technologies have been extensively accepted by patients since their development. The platform proposed in this study is aimed at dealing with these image data; it can provide a novel anatomy cerebrovascular disease detection platform for mobile devices with Android systems that can be applied in treatment of cerebrovascular disease, medical prevention, and health care.

E-Health(also written as e-Health) is an emerging term for healthcare practices supported by electronic processes and communication[2]. The concept of E-Health can be traced back to approximately 1999[3]. It refers to healthcare-related software that provides tools, processes, and communication means to support electronic healthcare practices. E-Health has rapidly developed since its inception. Jha et al.[4] assessed the state of health information technology (HIT) adoption and use in seven industrialized nations and found that many nations have achieved high levels of ambulatory electronic health record (EHR) adoption. However, there are also some challenges to E-Health implementation. Zhang et al.[5] have suggested that the healthcare industry lags behind various other economic sectors in the adoption of information technology in USA. Ludwick et al. [6] have investigated the current situation and the lessons learned in health information system implementation in seven countries, and the results were not very promising. For developing countries, the implementation situations are worse. Ssekakubo et al.[7] indicate that e-learning management systems in developing countries were inadequate. A longitudinal field study in a village in India also confirmed this result[8]. However, the level of research interest in the area of adoption and use of information and communication technology (ICT) in developing countries is currently increasing [9].

E-Health implementation has many advantages in healthcare, and there are several typical applications that considerably help individuals. Ruth[10] studied Text4baby, which uses new technology to deliver health messages and engage pregnant women and new mothers in healthy behaviors. Lei[11] proposed a novel, patient-personalized system for analysis and inference in the presence of data uncertainty, typically caused by sensor artifact and data incompleteness. The method was demonstrated using a large-scale clinical study wherein 200 patients were monitored using the proposed system. Yvonne[12] developed an agnostic clinical guideline decision support rule engine that uses classification and treatment rules for assessing a sick child defined in XML.

The continuous development of intelligent terminals makes the life and work of individuals more convenient and simple. Individuals desire the achievement of the same functions on an intelligent terminal as on a PC, which
can readily realize mobile office, mobile life, and mobile computing. Mobile health (M-Health, also written as mHealth) is a term used for the practice of medicine and public health supported by mobile devices [13]. Given the convenience that mobile phones offer individuals, M-Health will undoubtedly greatly change the lives of individuals with respect to healthcare [Error: Reference source not found]. Thus, M-Health is becoming increasingly important in E-Health. Norris et al. [15] conducted a pilot study on M-Health sustainability strategies and concluded that M-Health played and would continue to play a crucial role in healthcare. There are three key components in an M-Health service: mobile devices (such as smart mobile phones and tablet computers including iPads), server platforms (that provide basic services such as databases and corresponding data processing), and M-Health applications. At present, six major platform providers dominate the mobile platform market [16], and among the platforms, Apple’s iOS and Google’s Android are the most popular.

M-Health has developed very quickly since its inception. There are many mobile applications with different frameworks that are designed to increase the convenience of health care and disease treatment for individuals. Poon and Zhang [17] developed a four-layer M-Health application framework for their application to deal with an aging population problem and an increasing number of chronic patients in China. Broens et al. [18] presented a framework and evaluated it in an epilepsy patient monitoring system to support the development of context-aware M-Health applications. Raja [19] examined a prototype framework using several existing tools and technologies to address data collection for seasonal influenza. Furthermore, researchers have conducted work supporting and summarizing M-Health [20]. Laakko et al. implemented a Ubiquitous Personal Health Information Access (UPHIAC) platform to support the rapid and cost-effective development of M-Health applications. Whittaker et al. [21] also established a process for developing and testing mobile phone-based health interventions that was implemented in several M-Health interventions developed in New Zealand and that was a summarization for the development and evaluation process of M-Health. Liu et al. [22] examined the top 200 M-Health apps from the App Store from a developer's perspective to provide a focused overview of the status and trends of iOS M-Health apps and an analysis of related technology, architecture, and user interface design issues. Martínez-Pérez et al. [23] conducted a review and an analysis of the existing applications for mobile devices exclusively dedicated to the eight most prevalent health conditions.

In terms of medical informatics, advanced domestic hospitals have considerably progressed, including implementation of real-time recording; real-time transmission and processing of information about a patients' illness, medical records, and other information; sharing information in real-time within and between the hospitals via the internet to aid in expert consultations; remote treatment; and referral hospitals. There are seven stages of an intelligent medical system: the hospital business management systems of fee collection and drug management systems; electronic medical record systems including the management of the patients’ basic information and medical records; clinical applications like computer physician order entry system (CPOE); chronic disease management systems; regional health information exchange systems; clinical decision support systems; and public health and hygiene systems. China’s hospitals are currently in the first and second stages, and are moving toward the
third stage. The hospitals do not have a real sense of CPOE because of the lack of systematic uniform data standards and valid data. Moreover, most suppliers do not possess clinical backgrounds, making them unable to establish the criteria for practical applications. Current studies mainly focus on propelling the hospitals in China from stage two to stage five. This involves several industry standards and the formation of data exchange standards, which necessitates improvements in the future.

Among the existing smartphone operating systems, Android is becoming increasingly popular due to its open source encapsulation characteristics and high cost performance. In this study, a cerebrovascular mobile client was designed for cerebrovascular disease detection on an Android system with patient messages, brain scanning images, and a 3D cerebrovascular model transfer from the server to the tablet and mobile phone. Doctors and patients can utilize this platform to read the messages anytime and anywhere through the network. It would make it easy for a doctor to explain the illness to the patient and to consult with other doctors. Doctors can use the platform to a patient’s medical records, detect the patient’s MRI brain image sequences, and check the 3D cerebrovascular model. The mesh model in this study is more precise check and can be clipped, integrated, and calculated with future work, compared with the volume rendering on mobile devices [24]. The database structure of the server and the user access interface was defined and designed. The network protocol of the client and server were determined. The interface of the HTTP client protocol provided by Android was examined, and the exchange of information between the client and server was realized.

The rest of the paper is organized as below. The second section illustrates the five layer architecture of the entire system. The design of the server component of the system is introduced in the third section. The realization of the client component of the platform is described in the fourth section. In the fifth section, the functions of the platform are discussed and the performance of the platform is evaluated. The sixth section discusses the experiment, and the platform usage feedback is collected and an attempt is made to analyze and ameliorate user questions and comments. Finally, conclusions and implications for future work are presented.

The architecture of the platform

The aim of the platform is to transfer the text, images, and 3D models from the server to the client. The data management method, the transfer mechanism, and the message processing were the key technologies in the system. A five layer architecture comprising an application layer, a processing layer, a service layer, a data layer, and a network layer was designed for the platform. The details are shown in Figure1. The application layer was the interface of the platform. The processing layer mainly deals with the medical data analysis and data caching. The service layer handles data acquired from the data layer according to the instructions from the application layer, and the results are returned to the application layer for corresponding requests. The data layer establishes a solid foundation for all the upper levels and provides a connection between the multiple data. The network layer involves the underlying transport of messages in the WLAN.
**Application Layer:** There are five functional parts for users: user login, information inquiry, information classification, medical imaging management, and three-dimensional (3D) model display. Doctors can login to the system with a specific username and a corresponding password. The system also provides approaches for the doctor to query the basic information of different patients. Various types of information will be clearly classified according to the information properties and inspection dates so that doctors can better manage medical imaging. The cerebrovascular medical data will be displayed in the form of pictures and 3D models. The mobile terminal sends a request to the server when doctors use the system, and the server responds with different responses depending on the instruction.

**Processing Layer:** The medical data analysis part is designed to process raw medical data such as computed tomography (CT) or magnetic resonance imaging (MRI) that are too large to be directly displayed in the Android system. The raw data is transformed into joint photographic experts group (JPEG) format to compress the data. As the data accuracy and information can be lost during this process, an efficient solution for the problem was put forth. This involved accelerating the response speed by importing a data caching mechanism, which can store the processed data into the buffer area and perform a burst transmission when required.
Service Layer: The service layer comprises three modules: rights management, message handling, and system log management. The rights management mechanism provides privileges of memory access control to the system, which can improve the system security. The message handling mechanism is mainly used for processing all types of messages that are received from the application and data layers and for sending the processed results to the application layer in a timely manner. System log management is very significant in the programming. The log management recorded all system behaviors to enable program debugging and extensions when needed.

Data Layer: Data is classified and saved according to its properties. The data relationships can be built and stored such that it is more convenient and quicker to retrieve the data. The basic information of doctors and patients is classified as user data. Resource data refers to the original medical image data and...
cerebrovascular processed data, which can be obtained from hospitals and educational and research institutions with cerebrovascular processing platforms.

**Network Layer:** Most internal hospital management systems use wireless local area networks (WLAN) connections, and therefore, the system developed in this study is compatible for use with a WLAN connection. There are two types of data streams. The first type of data stream involves a sequence of instructions, and the second includes various types of data. The doctor uses a client to generate a sequence of instructions in the application layer. The network layer can receive the orders from the application layer and send them to the service layer. The corresponding data can be read from the data layer according to the command and passed from the service layer to the process layer. Following this, the processed data will be sent back to the application layer via the network layer, corresponding to the service layer.

**Design of the server component**

**Server model based on an event-driven model**

The mobile E-Health platform in this study supported the concurrency of multiple clients. Hence, the easiest solution to cope with multi-client network applications is to use multiple threads (or processes) on the server. The purpose of multithreading (or multiprocessing) is to allow a separate thread for each connection so that the block of a connection does not affect other connections. There is no specific pattern for using single thread or multithreading. Traditionally, the cost of a process considerably exceeds that of the thread, and therefore, multiprocessing is not recommended when the number of clients requiring the service is large. However, the process is much safer when a single service is executed as this consumes more central processing unit (CPU) resources, such as the need for large-scale or long-term data operation or file access. Herein, a multi-threaded approach is used to respond to a new user's connection. The server can satisfy the provision of a question and answer service for multiple clients in real-time using ClientThread( ) to create a new user thread.

The main thread continuously waits for a connection request from a client. If there is a connection, a new thread is created, and it will provide the same question and answer service as the preceding thread. A socket can be accepted multiple times. The interface accept( ) can return a new socket, and its prototype is as follows:

<table>
<thead>
<tr>
<th>Parameter 3</th>
<th>socklen_t *addrlen</th>
<th>the size of the structure returned in the addr parameter</th>
</tr>
</thead>
</table>

Table 1. Description of function accept()

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function name</td>
<td>int accept()</td>
</tr>
<tr>
<td>Parameter 1</td>
<td>int s</td>
</tr>
<tr>
<td>Parameter 2</td>
<td>struct sockaddr *addr</td>
</tr>
<tr>
<td>Parameter 3</td>
<td>socklen_t *addrlen</td>
</tr>
</tbody>
</table>

The input parameter s is the handle from socket(), bind(), and listen(). After
the execution of bind() and listen(), the operating system started to listen to all the connection requests at the specified port (which was 9999 in our M-Health tool). If a new user connection request is received, it is added to the request queue. Invoking the interface accept() involves extracting the first connection message from the request queue, creating a new socket, and returning the handle. The returned handle is the input parameters of read() and recv(). If at the time of sending there is no request in the request queue, the interface accept() enters the block state until any requests enter the queue. The multi-threaded server model can conveniently and efficiently meet the needs of the mobile E-Health platform.

The above model mainly simulates a “question and answer” service process. Thus, if the listening thread detects the capture of the “readable event” by a handle, the server program operates recv() in time and prepares the transmission data according to the received data, and the corresponding handle is saved for detecting the next “writable event” thread. Similarly, the server program operates send() if the listening thread detects the capture of the “writable event” by a handle, and prepares for detecting the next “readable event” thread.

Figure 2 shows an execution cycle of a new user connection in the multi-threaded server model. This model is termed as an “event-driven model.” The model feature of this model includes the detection of an event or a set of events during each execution cycle by the system, and a particular event triggers a particular response. The event-driven model only uses single-threaded execution, which consumes fewer resources and does not occupy too much CPU, while providing services to multi-clients.

Network communication protocol

Client active communication mode is used for communication between the server and the client. The client sends commands initatively, and the server performs the corresponding operations and returns the results. The
communication between the server and the client used the hyper text transfer protocol (HTTP) client defined in the HTTP protocol. There are two ways of communication: the GET operation and the POST operation. The GET operation mainly involves reading information from the server. The POST operation modifies the server content or queries the server contents with parameters.

Hence, the GET operation containing query subscription information is used to login. The POST operation is mainly used in customizing related business interactions with the client. The process of initiative communication between the client and the server is shown in Figure 3. If the client wants to modify the server content using POST with parameters, an HTTP Post object is first established for parameter transmission and the server IP address. This is similar to the process of the GET operation.

![Diagram of initiative communication between client and server](image)

**Figure 3. Initiative communication between the client and the server**

**Message mechanism**

The server platform defines the entire message instructions and establishes a good communication mechanism between the server and the client. The client transmits the messages by creating an object named NetCmd and generates control packets with different parameters. The first parameter is a number, and different numbers indicate different demands. The rest involve data that need to be translated. Simultaneously, the server creates an object named NetData for data transmission. The data is partly transmitted if it was too large. For example, the client transmits a message via a control package with two parameters: NetCmd.CmdType.doctorVerification and username, when verifying user login authority. The first parameter indicates that the doctor's name requires...
verification, and the second parameter indicates the name to be verified. The message of requesting digital imaging and communications in medicine (DICOM) image thumbnails from the server is a control package with three parameters: NetCmd.CmdType, patientID, NetCmd.DataType.pictureSmall, and cmddomain. The first, second, and third parameters indicate that the translation of data is involved, that small pictures are involved, and the name of the data, respectively.

The server workflow is as follows: when a server starts, it broadcasts its IP address and creates a listening thread. It also opens up a client thread every time a client connects. This is the abovementioned multi-threaded model. The server listens to client messages circularly from the client threads. When the server receives a message, it reads data from the database according to the message content. Then, it calls the corresponding server programs for data analysis and returns the results to the client. Note that not all operations require corresponding programs for data analysis. In some operations such as data queries, only reading the data from the database and transmitting it back to the client is required.

The Multicast transmission is a one-to-many network connection between the sender and multiple receivers. The server transmits the same data package to every client that is available. Hence, any client who wants to connect the server knows where to send the message. This improves the data transmission efficiency and reduces the congestion possibility in the backbone network. Using multicast technology, which is suitable for relatively independent environments such as hospital LAN, we realized an automatic connection to the server and the reduction of additional operations like typing in the IP address manually.

**Design of the mobile client part**

The development of a client platform is based on Eclipse with Android software development kit (SDK) and is used to complete the Android software application design. In this section, a brief description of the entire project software structure running in the Eclipse environment is provided.

The client platform uses a MVC model. MVC is a software design pattern comprising three basic components: a logical model (M), a view model (V), and a controller (C) [26, 27]. In the client development, M refers to the binary data and V refers to the user interface. Typically, XML files are directly used to save M and V, thereby making it more convenient for development. C refers to an activity that has multiple interfaces. We displayed the specified view model by passing out the view ID using setContentView(). The biggest advantages of development using the MVC model is the complete separation of the logical and view model developments, which helps in improving code reuse and development speed [28]. The MVC structure of the client is shown in Figure 4.
Text transmission

In the system, all the data information use HTTP protocol in the transmission network. The client and the server control the receipt and sending of data by instruction and message response mechanisms. The text information mainly includes various types of messages stored in the DICOM File Meta Information.

DICOM File Meta Information contains information to identify data sets. Every DICOM file must be included in the file header. The beginning of the file header is a file preface, followed by a DICOM prefix, which has a length of 4 byte string for identifying if the file is a DICOM file. A data element is mainly composed of four parts, namely, the label, value representation (VR, i.e., data description), data length, and data fields. The label was a 4-byte unsigned integer, and it was divided into two parts, namely, the group number (upper 2 bytes) and the element number (lower 2 bytes). The value of VR indicated the type of the data element. The DICOM file is a string of length 2. For example, “DA” indicates that the data stored in the data element is the date data type, and “FL” indicates that the data stored in the data element is a floating-point data. The length of the data elements indicates the data length of the data field. The data field contains the value of the data element. All labels have a fixed position, and by reading the information corresponding to the label, we can obtain the patient’s name and other basic information.

The instruction comprises three parts: command type, data type, and parameter domains. The command type provides the functions to be achieved, the data type specifies the data needed, and the parameter domains offer the parameter required to fulfill the task. This unified design reduces the complexity of communication and ensures correct and effective client work.

Image transmission

The brain MRI sequence of a person comprises more than two hundred slices. For each slice, the data is 512*512. However, generally, the doctor only sees the entire sequence, and only a few slice images are studied in detail. It would be very expensive for the network to transfer all the DICOM data to the client part and may not be necessary for the doctor's use.

In the server, the MRI sequence is compressed to the JPEG sequence, and the
JPEG sequence is transferred to the client. It is observed that gridding is the most suitable display format for the tablet screen size. If the doctor wants to study an image in detail, he/she touches the image on the tablet screen and the server can transfer the DICOM data corresponding to this image. Two problems are solved in the process. One problem involves the method of compressing the DICOM to the JPEG, and the other involves methods to correlate the JPEG and DICOM data.

**Adjusting and Converting DICOM files into BMP/JPEG**

The original pixel data resolved from DICOM files are associated with the acquisition devices and cannot be displayed directly without the need for conversion operations. The dynamic range of ordinary graphics cards is limited, and hence, only 256 gray scale images can be displayed. Therefore, the image processing system should convert the image data of the region of interest and select pixel values of the specific range to enable easy access for doctors. This can be achieved with a linear algorithm to adjust the window width and level or a nonlinear algorithm of searching lookup table (LUT). In this study, the former method, i.e., adjusting the window width and level, is used.

Adjusting the window width and level implies converting the image data of the window area to the maximum range of the displayer linearly based on the value of exiting window width and level. The window level represents the center value of the image displayed, and the window width indicates the display range of the image data. The corresponding equation is as follows (Formula 1), where $V$ is the image data, $G$ is the value of the displayer, $\delta m$ is the maximum value of the displayer, $W$ is the window width of the image, and $C$ is the window level of image.

$$G(V) = \begin{cases} 0, & V < C - \frac{\omega}{2} \\ \frac{\delta m}{\omega} (V + \frac{\omega}{2} - C), & C - \frac{\omega}{2} \leq V \leq C + \frac{\omega}{2} \\ V > C + \frac{\omega}{2} \end{cases}$$  

In the previous section, we mentioned the necessity to resolve the DICOM data on the server; this was achieved using VTK to convert DICOM data to JPEG format on the server. The original DICOM data is obtained from the database and is read into the memory by `vtkDICOMImageReader` for the next processing preparation. Then, we adjust the window width and level of the image. After that, the processed data is converted into data in JPEG format by `vtkJPEGWriter/vtkBMPWriter` and then transmitted to the client. There are two benefits to this method. The first benefit is the removal of the header, which is large but not necessary for transfer after extraction. The second benefit is the compression of the data size by converting the data into JPEG format. Additionally, the processed data is stored in the memory and directly transmitted to the client in order to improve the transmission efficiency and reduce transmission time. The data is filled in the Gridview adapter directly after the client receives the data, and then, the doctor can view the image.

Note that the most appropriate window width value and window level ensuring the best effect of display differs between the various sets of medical image data. However, the window width and level values of the cardiovascular data is roughly the same as those of the cerebrovascular data. The images are
shown to have different precisions for the client. The precision of JPEG/BMP images can be changed by calling the function SetQuality during data processing using `vtkJPEGWriter/vtkBMPWriter`.

**Correspondence between thumbnail and high-precision image**

Note that due to the internal mechanism, the reading order of VTK is not in accordance with the file name when reading a set of medical image data using `vtkDICOMImageReader`. Since the machine collects the slices in a special way, the file name order is not necessarily the correct sequence of medical images. The high-precision image received by clicking on the file name of the thumbnail is not the corresponding image if the data transmission method was through thumbnails. This is the correspondence problem. A method of preprocessing to solve the problem is proposed. The original DICOM data is sorted according to the VTK internal mechanisms before importing the data to the database. Then, the corresponding file name is the correct sequence of the medical image[29].

**3D model transmission**

OpenGL for Embedded Systems (OpenGL ES) is a subset of the OpenGL 3D graphics API for devices like mobile phones, PDA, and video game consoles. This is used in the system for 3D model transmission.

The technology that generates images, video signal, or filmstrip using models or scenes is called rendering. Images and vertex coordinates are closely related, and the relationship is given by the drawing mode. Pipeline, also known as rendering pipeline, is a series of operation performed by OpenGL ES to process and render data. During the process of rendering, similar to pipeline operations, one operation is followed by another and this significantly improves the rendering efficiency.

**Parsing of Obj Model File**

The segmentation and construction of brain MRI data enables the cerebrovascular 3D model with *.obj. It supports normal and texture coordinates. It is a static object that can be quickly loaded into display scenes. The original 3D data model is an *.obj model file that cannot be directly displayed on the Android client and needs to be parsed. The OpenGL ES 2.0 Graphics Pipeline is shown in Figure 5.

![OpenGL ES 2.0 Graphics Pipeline](Image)

**Figure 5. OpenGL ES 2.0 Graphics Pipeline**

In addition to illustrative contents, each line in an obj model file starts with a
letter that represents a different type of data. After this, the corresponding content in the specified format is provided. The lines starting with the letter "v" follows with three float-point values as the position of a vertex. The lines start with the letter "vt" followed with two float-point values representing the texture coordinates. The letter “vn” is followed by three float-point values representing the normal. Typically, three pairs of index values follows the letter “f,” with each pair comprising three index entries. The first entry represents a vertex, the second entry indicates the texture coordinate of the vertex, and the third entry refers to the normal in the vertex. The three vertexes composed a triangle. A triangular model could be generated for display using these data.

The method of allocating memory for storing data in advance is used to load a file. It is more efficient than the method of allocating memory when needed. These operations are conducted on the server side by considering the computing power of the android client hardware. Then, the parsed data is transferred in the form of a data stream to the client. Multithreading is used for rendering the client, which greatly saves rendering time.

**Obj model file simplification**

Since the original obj model files are large and time-consuming during the process of transmission and display, we use a simplification method to simplify the obj model file under the premise of maintaining display effect.

To guarantee no severe loss of the visual features of objects, the mesh simplification algorithm represents objects with a smaller number of polygons. This reduces the model complexity and improves the rendering speed. The differences in the blood vessel surface curvatures are not large. Hence, according to the value of the normal of the vertex, the edge contraction mechanism is used to shrink edges in the coplanar area and merge the collinear feature edges. During this process, the feature points are retained, and the change of the normal of vertices and faces are maintained within a certain range, which retains the visual effect of the model[30].

The basic steps are as follows:

**Step 1:** The normal vector of each vertex is calculated.

**Step 2:** All the edges of the grid are sorted by length and the short edges are placed at the head of the queue.

**Step 3:** Beginning from the head of the queue, the edges whose inclined angle of the normal vectors on two vertices is less than or equal to a user-specified threshold value are removed, and the shrink operation is executed.

**Step 4:** The length of edges and normal vector of vertexes that are affected are recalculated and the queue is adjusted.

**Step 5:** Steps (3) and (4) are repeated until the contractible detected edges are not detected. A conventional simplification is performed.

**Step 6:** The threshold is increased and steps (3)–(5) are repeated for relatively short edges. A simplified cycle is completed.

**Step 7:** The mesh vertices and the normal surfaces are cleared if necessary and steps (1)–(6) are repeated for multiple simplified cycles.

During the simplified process, every time an edge is shrunk, the vertices reduce by one with the edges reducing by three and triangles reducing by two. On the premise of ensuring the effectiveness, the data size and calculation time
can be significantly reduced. Additionally, after simplification, all *.obj models will be corresponded with the original DICOM image data and stored in the database. When required, it will be translated under the WLAN environment, which significantly reduces transmission time.

The platform used in the cerebral vessel disease detection/heart disease detection

The server runs on a 64-bit system with the CPU of Intel(R) Xeon(R) CPU E5-2650 v2 @ 2.60 GHz (2 CPU) and 32.0GB of RAM. The java version is 1.8.0_11, and eclipse is used as the compiler with the SDK of Android 4.1. The SQL Server 2008 database is used. The client runs on a SAMSUNG NOTE N8000. This included a 4 kernel Exynos4412 CPU 1.4GHz, a DDR3 2G RAM, and 16GB of ROM. Its operating system is Android 4.1.2.

The design of client interface and logical workflow

1) Overall design

The interface flow design of the client is shown in Figure 6. The system screen is mainly divided into four parts: login, patient information, data selection, and medical imaging display screens. The doctor can obtain the required information by selecting the appropriate option after successful login.

![Figure 6. The interface flow design of the client](image)

2) Login screen

The login screen is the first screen seen after starting the client. The network connection status, time, battery power, and program title bar are shown at the top of the screen. A system logo is in the middle of the screen and it follows the user login input box, “Login” button, and the “reconnect to server” button.

Since the system uses the LAN, multicast is provided. The client can search the server and automatically connect to it when the client starts so that it can make the operation more concise and eliminate the need for users to enter the server's IP address. However, if the server connection is unsuccessful, the user can click the “reconnect to server” button and manually enter the IP address in the pop-up dialog that can connect the server successfully, as shown in Figure 7. The input box for recording the login information uses "Edittext" control with which the system can call the soft keyboard for input. The password input box adds the property of “password” that can turn characters into black dots after entering the characters in the password box in a second. This prevents “shoulder surfing” and protects the privacy of users. After the information is entered, click on “Login” to start the system, as shown in Figure 8.
3) Patient selection screen

Following successful login, the selected patient information interface is shown (Figure 9). The list name is on the top of the screen, and below this, the head portraits of the patients are displayed on the left with their basic information including names, medical record numbers, and date of birth on the right side. The registered doctor diagnosis all the patients shown. Each item in the list is monitored so that the doctors can click on each line to select the medical information data of the specified patient.

Unlike other mobile medical systems, “Textview” is not adopted but “ListView,” combining text and images, is adopted in the system to display patient information. As the patient information to be displayed is broadly similar, “ListView” is applied to this screen, making the interface simple. Each item in the list is used in the relative layout, which makes the overall effect more vivid. From the interface design standpoint, the design allows access to the patient information at a glance without requiring any extra operations.

4) Data selection screen

Multilevel lists are adopted in the data selection interface in Figure 10. The first level list is divided into three groups: cardiovascular raw data display, cerebrovascular raw data display, and 3D model display. The second level list is filled with different kinds of medical imaging data, distinguished by acquisition time. In terms of 3D models, as both cardiovascular and cerebrovascular data may be involved for a patient, it is necessary to identify each item in the second list by naming a body part in addition to the collection time.

At the beginning, three buttons are used to represent the three groups of the first-level list. After the button is clicked, the system jumps into three different screens to show corresponding data selection time lists. Although it is functional, it is replaced by the final design for two reasons. The first reason involves simplifying programming. In the previous designs, three extra activities are
required to fulfill the function, which occupies system resources while the system is running; only a list of time with roughly the same type is shown. After improvements, the data collection time is shown as a second-level list in the same activity. This simplified the programming complexity. The other reason is that from the user perspective, doctors can search all the medical data of the patient queried in the same screen, which can also precede operations.

5) Medical imaging display screen

The display of medical images is divided into two types, namely, the two dimensional (2D) display of cardiovascular and cerebrovascular data, and the 3D model display. A grid form is applied for the 2D medical images shown in Figure 11 and Figure 12. The doctor can locate the images of interest by sliding the screen and achieve high-definition images by clicking on specific images. The system provides a history function by recording each image of interest selected by the doctor. The doctor can slide the screen left and right to reach all the selected images for comparison when viewing the high-definition images. This is more conducive for doctors to diagnose illness. The parameters of light and texture mapping are set for 3D models to render 3D models with the help of Android OpenGL ES, which also provides zoom and rotation functions.
6) 3D model display screen

The objective model was simplified as mentioned above to provide a fast view of the 3D model. Additionally, for the purpose of facilitating a doctor's diagnosis, a variety of interactive tools like zoom, rotate, and translation are offered. Furthermore, a lighting model is added for a more realistic effect with the help of OpenGL ES 2.0, as shown in Figure 13, to ensure good visual effects.

![Figure 13. 3D model display](image)

**Evaluations**

The system can meet multi-user concurrent requests. Given that the client is configured to meet the appropriate Android system and has installed the system, the client could connect to the server via the network. It is also possible to
connect to the server with Android phones and tablets while reading the patient data. Table 2 shows the result of simplified JPEG data.

The thumbnail transmission time of a 312 cardiovascular JPEG data from the server to the client and full display was approximately 4.24s. A single thumbnail insufficient transmission time is less than 1s, which is almost negligible. The original DICOM data size is 159MB, the JPEG data size is 2.25MB, and a single JPEG image size is in the range of 3.61 to 4.88KB. The thumbnail transmission time of a 268 cerebrovascular JPEG data from the server to the client and full display is approximately 3.70s. A single thumbnail insufficient transmission time is 1.04s. The original DICOM data size is 300MB, the JPEG data size is 2.08MB, and a single JPEG image size is in the range of 3.79–5.91KB. The thumbnail transmission time of a 136 cardiovascular JPEG data from the server to the client and full display is approximately 3.95s. A single thumbnail insufficient transmission time is 1.08s, which is also negligible. The original DICOM data size is 69.5MB, the JPEG data size is 766KB, and a single JPEG image size is in the range of 4.13–6.26KB. Table 2 is the comparison of the DICOM data and the simplified JPEG data. HD means cardiovascular DICOM data, BD means cerebrovascular DICOM data, DSize means size of DICOM data, and JSize means size of JPEG data. Time refers to the translating time of a set of JPEG data.

Table 2. Comparison of DICOM data and simplified JPEG data.

<table>
<thead>
<tr>
<th>Part</th>
<th>Number</th>
<th>DSize</th>
<th>JSize</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD</td>
<td>312</td>
<td>159MB</td>
<td>2.25MB</td>
<td>4.24s</td>
</tr>
<tr>
<td>BD</td>
<td>268</td>
<td>300MB</td>
<td>2.08MB</td>
<td>3.70s</td>
</tr>
<tr>
<td>BD</td>
<td>136</td>
<td>69.5MB</td>
<td>766KB</td>
<td>3.95s</td>
</tr>
</tbody>
</table>

The time of a 2.00MB obj model parsed on the server and transmitted to the client and full display is about 1.43min. The delay is mainly dependent on the model size and network status. If the original model is small and the network transfer rate is high, the response delay to the client will be much smaller. For the DICOM data, the original data size has little effect on the response delay. Hence, there were negligible requirements to the original data. However, for the 3D model data, the impact of the original data size on data analysis and network transmission delay is large. Therefore, the original data size of the 3D models is limited to 2MB.

**Experiment**

A comparative study was conducted to collect feedback from users of the platform and to ameliorate problems discovered by users. This helps in assessing if the platform has all the necessary functions and what needs improvement according to the results. The experiment was conducted both among the general public and at some hospitals during 2015.

As previously discussed, the platform was designed for both common and professional users. Hence, the experiment was conducted separately. The first group of the subjects comprised members of the general public from various occupations and included both undergraduate and postgraduate students. All the subjects had no medical science background and represented common users. The other group comprised doctors from Beichen hospital and Tianjin Jinghai hospital, represented professional users. All the subjects were requested to install and use the platform on their cell phones for more than two weeks.
Following this, the subjects were requested to fill in a questionnaire designed to collect their feedback.

In this section, preliminary studies such as the experiment methodology and the questionnaire questions are first discussed. Then, the results from the questionnaires collected from the subjects are analyzed and compared. Finally, the conclusions of the experiment are discussed and future work is outlined.

**Preliminary research**

A pilot study was conducted prior to the experiment to determine the acceptance of this platform as well as the degree of user satisfaction.

The first group included students from Beijing Normal University. A total of 40 students were evaluated, which consisted of 18 (45.0%) female students and 22 (55.0%) male students. The ages of the subjects varied from 19 to 31 years, and the average age was 24.43 ± 9.64 years. The education background of the subjects was good and most subjects (80%) were graduates. All participants consented to take part in the study, and their cell phones were appropriate for installation of the platform.

Additionally, 21 doctors from Beichen hospital and Tianjin Jinghai hospital also participated in the evaluation. This included 13 females (61.9%) and 8 (38.1%) males. The ages of the doctors varied from 27 to 40 years, and the average age was 32.14 ± 4.42. All the subjects possessed a master’s degree and consented to take part in the study.

Figure 14 and Figure 15 show the sex and age distribution for all the participants in the experiment. The student group represented common users, whereas the doctor group represented professional users. The distribution shows that the experiment was mainly performed for young people aged between 20 and 30 years, which was also the target population of the platform. In the experiment, the platform was installed in all the subjects’ cell phones, and then, the subjects were taught to use this platform.

![Figure 14. Sex distribution for the two group participants](image1)

![Figure 15. Age distribution for the two group participants](image2)

The subjects were asked to fill in an anonymous questionnaire after a few weeks to gauge their level of satisfaction with the mobile application. The research questions to be answered included whether the participants valued the platform as a platform with high performance and complete functions, whether participants valued the platform as a learning tool, whether the platform was an
appropriate tool for cerebrovascular disease detection, and whether the platform could be extended for the detection of other diseases such as respiratory and cardiovascular diseases.

The questionnaire can be divided into 3 parts. The first part involved the participant’s basic information, the second part included feedback about the performance and functions of the platform, and the last part concerned the platform contents.

Specifically, the questionnaire contained 20 questions, including 19 limited response questions and 1 space limited free-text question. These questions covered the basic information of the participants (question Q1–Q4), the experience of the usage of the platform (questions Q5–Q11), and the users’ opinion about the platform contents (Question Q12–Q21). Note that in Q20 and Q21, a contrast was made between the platforms in this study, a real brain model, anda3D Slicer. This is illustrated in Figure 16–Figure 18.

![Figure 16](image1.png) The mobile platform used in this study
![Figure 17](image2.png) Traditional silicone brain model in Q20
![Figure 18](image3.png) Platform of 3D Slicer in Q21

The questionnaire ended with an open question inviting suggestions of improvements for the application. Questions Q1–Q4 were single choice questions. Questions Q5–Q11 were answered using a five-point Likert scale where 1 represented “very bad” and 5 represented “very good.” Questions Q12–Q21 were also answered using a five-point Likert scale, but here 1 represented “strongly disagree” and 5 represented “strongly agree.” In questions Q22, participants were given free space to write their answers.
The results for the questionnaires were analyzed using statistics, and the results for the two groups are shown separately. The differences between the two groups are also discussed. All the results are expressed using the form of mean and variance.

Comparative analysis

In this experiment, 61 questionnaires were distributed and the response rate was 100%. Here, Q5 is considered as an example to show the computational procedure and the meaning of the evaluation results by conducting the following analysis.

After collecting the questionnaires from the two groups, the raw results of both common and professional users were input into IBM SPSS Statistics V22.0 (a software package used for statistical analysis) to perform the calculations.

Figure 19 and Figure 20 shows the histogram of the two groups for Q5. The x-coordinate represents the five-point Likert scale answered by users, whereas the y-coordinate represents the frequency of occurrence. The curve in the figure is the Gaussian curve. According to the text in Figure 19, the mean for professional users is 3.52, the variance is 1.03, and the total number of subjects in the group is 21. Similarly, the text in Figure 20 shows that the mean for common users is 3.5, the variance is 1.038, and the total number of subjects in the group is 40.

The independent sample t-test was conducted to compare if there was a difference in the means of the two independent samples (professional and common user groups) for Q5. Table 3 shows the results of the independent–sample t-test for the professional and common user groups for Q5.

<table>
<thead>
<tr>
<th>Levene’s Test for Equality of Variance</th>
<th>t-test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sig</td>
</tr>
</tbody>
</table>

Figure 19. Histogram of the professional user group for Q5

Figure 20. Histogram of the common user group for Q5

The independent sample t-test was conducted to compare if there was a difference in the means of the two independent samples (professional and common user groups) for Q5. Table 3 shows the results of the independent–sample t-test for the professional and common user groups for Q5.
The results in Table 3 can be divided into two parts, the first of which was Levene’s test for equality of variances. This was used to judge whether the homogeneity of variance of the two groups was optimal. The second part showed the t-test for equality of means in both situations where the homogeneity of variance was optimal and situations where the homogeneity of variance was not optimal. According to the data shown in Table 3, Sig. equals 0.881, which is higher than 0.05, and this indicates that the homogeneity of variance is optimal. Hence, the following judgments can be used for the data when the row of equal variances is assumed. The value of Sig.(2-tailed) in this row is 0.932, which is higher than 0.05. This means that for Q5, according to the sample, there is no significant difference between professional and common users.

Then, the analysis procedure described for Q5 was extended to all the remaining questions, and the final results for Q5 to Q19 are illustrated in Table 4.

In Table 4, there are five columns. The first column is the question from the questionnaire, the second and the third columns show the results (mean and variance) of the common and professional user groups, respectively, the fourth column shows the difference in the means of the two groups, and the last column shows the results of the independent–sample t-tests. Here, N represents that for this specific question, there is no difference between the professional and common users, whereas Y represents that there is a difference between the professional and common users. When the results moved forward by a single step, the difference is mainly reflected in the difference of means between the two groups.

Table 4. Statistical results of both professional and common user groups from the questionnaire

<table>
<thead>
<tr>
<th>Questions</th>
<th>Common users (mean+variance)</th>
<th>Professional users (mean+variance)</th>
<th>Difference</th>
<th>Independent–sample T-test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q5. The aesthetic measure of the interface</td>
<td>3.50 ±1.04</td>
<td>3.52 ± 1.03</td>
<td>P=0.02</td>
<td>N</td>
</tr>
<tr>
<td>Q6. The stability of the application</td>
<td>4.30 ± 0.70</td>
<td>4.29 ± 0.62</td>
<td>P=0.01</td>
<td>N</td>
</tr>
<tr>
<td>Q7. Ease of use for this application</td>
<td>3.92 ± 0.63</td>
<td>4.33 ± 0.51</td>
<td>P=0.59</td>
<td>N</td>
</tr>
</tbody>
</table>
The evaluation of the experiment was quite positive. For part 2, all evaluations were above 3 (range 1–5). The complete statistical results for the two parts are depicted in Table 5.

The difference between these two groups is very small in part 2, which implies that the usage experience of the platform by the two groups is similar. The difference between the two groups mainly lies in part 3, because of the differences in professional backgrounds and because the degree of satisfaction for the platform contents is different.

<table>
<thead>
<tr>
<th>Question</th>
<th>Common users (mean ± variance)</th>
<th>Professional users (mean ± variance)</th>
<th>Difference between the two groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q8. The interactivity of this application</td>
<td>4.00 ± 0.43</td>
<td>3.91 ± 0.95</td>
<td>P=0.09 N</td>
</tr>
<tr>
<td>Q9. The response speed of this application</td>
<td>3.85 ± 0.87</td>
<td>3.94 ± 0.77</td>
<td>P=0.09 N</td>
</tr>
<tr>
<td>Q10. The notification frequency of this application</td>
<td>3.45 ± 0.60</td>
<td>3.20 ± 0.93</td>
<td>P=0.25 N</td>
</tr>
<tr>
<td>Q11. The fluency of this application</td>
<td>3.92 ± 0.74</td>
<td>3.86 ± 0.74</td>
<td>P=0.06 N</td>
</tr>
<tr>
<td>Q12. The fully functional of this application</td>
<td>2.85 ± 0.42</td>
<td>3.00 ± 0.49</td>
<td>P=0.15 N</td>
</tr>
<tr>
<td>Q13. The contents are professional</td>
<td>4.52 ± 0.50</td>
<td>3.64 ± 0.87</td>
<td>P=0.88 Y</td>
</tr>
<tr>
<td>Q14. Can solve the problem effectively</td>
<td>3.36 ± 0.66</td>
<td>3.86 ± 0.79</td>
<td>P=0.50 N</td>
</tr>
<tr>
<td>Q15. The communication between patients is very helpful</td>
<td>3.60 ± 0.66</td>
<td>4.00 ± 0.97</td>
<td>P=0.40 N</td>
</tr>
<tr>
<td>Q16. The medical knowledge in this application is helpful</td>
<td>4.82 ± 0.55</td>
<td>3.57 ± 0.75</td>
<td>P=1.25 Y</td>
</tr>
<tr>
<td>Q17. It’s a new convenient experience</td>
<td>4.41 ± 0.72</td>
<td>3.76 ± 0.82</td>
<td>P=0.65 N</td>
</tr>
<tr>
<td>Q18. Would you like to pay for the service</td>
<td>3.01 ± 0.47</td>
<td>4.19 ± 0.59</td>
<td>P=1.18 Y</td>
</tr>
<tr>
<td>Q19. It is very convenient and save a lot of time</td>
<td>4.10 ± 0.30</td>
<td>3.87 ± 0.99</td>
<td>P=0.23 N</td>
</tr>
<tr>
<td>Q20. Compared with the brain model, this platform is easier to observe</td>
<td>3.92 ± 0.65</td>
<td>4.01 ± 0.44</td>
<td>P=0.09 N</td>
</tr>
<tr>
<td>Q21. Compared with CT image, this platform is more portable</td>
<td>4.17 ± 0.55</td>
<td>3.79 ± 0.76</td>
<td>P=0.38 N</td>
</tr>
</tbody>
</table>

The evaluation of the experiment was quite positive. For part 2, all evaluations were above 3 (range 1–5). The complete statistical results for the two parts are depicted in Table 5.

The difference between these two groups is very small in part 2, which implies that the usage experience of the platform by the two groups is similar. The difference between the two groups mainly lies in part 3, because of the differences in professional backgrounds and because the degree of satisfaction for the platform contents is different.

Table 5. Statistical results for the whole two groups

<table>
<thead>
<tr>
<th>Part</th>
<th>Common users (mean ± variance)</th>
<th>Professional users (mean ± variance)</th>
<th>Difference between the two groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part2</td>
<td>3.849 ± 0.716</td>
<td>3.864 ± 0.793</td>
<td>P=0.015</td>
</tr>
<tr>
<td>Part3</td>
<td>3.876 ± 0.548</td>
<td>3.768 ± 0.747</td>
<td>P=0.108</td>
</tr>
</tbody>
</table>
The last part of the questionnaire was an open question, and the results between the two groups were quite different. The results are shown in Figure 21 and Figure 22. According to these figures, common users concentrate more on the aesthetic aspects of the interface, whereas professional users concentrate more on the understandability of the results.

**Discussion**

As discussed above, a comparative study was conducted to collect the usage feedback of the platform and ameliorate the questions asked by users. According to the comparative analysis, the evaluation of the experiment was quite positive. The experience of the platform usage across both groups was quite good. The statistical results for both groups were higher than 3.8 (range 1–5). This indicated that both common and professional users were satisfied with the platform.

The differences between the two groups were mainly focused in part 3, and specifically in Q13, Q16, Q18 (independent-sample t-test result was Y), and the open question. In Q13, professional users appeared to consider that the platform contents were less professional. In Q16, the results indicated that common users considered that the medical knowledge in this application was more helpful. In Q18, observations revealed that most of the professional users were willing to pay for this application, while most of the common users thought that the application should be free. Additionally, according to Q20 and Q21, both professional and common users considered that the platform was easier when compared with the real brain model and that the platform was more portable than the CT image.

The results of the open question are depicted in Figure 20 and Figure 21. According to these two figures, the suggestions for both groups included increasing data privacy, enhancing the understandability of the results, providing diagnosis conclusions for the patient, and increasing aesthetic measures of the interface. However, most of the doctors paid close attention to the understandability of the results and diagnosis conclusions, while more than half of the common users kept a watchful eye on the aesthetic measure of the interface. The difference shows that the platform contents were appropriate and sufficient for a common user, while the contents were insufficient and unduly simple for a professional user.
According to the discussion for the experiment, individuals were basically satisfied with both the experience of the platform usage and the platform contents. They considered that the platform was easier to observe when compared with the real brain model and that the platform was more portable when compared with a CT image. Furthermore, there were some areas for improvements, including increasing the understandability and providing diagnosis conclusions.

**Conclusions**

This paper presented a new mobile E-Health platform for cerebrovascular disease detection. It is a valuable study that can help other researchers develop innovative E-Health platforms that can make disease detection and treatment more convenient for patients. The purpose of this study was two-fold. The first was the application of new tools for doctors and patients in real diagnosis. The second was to assess the impact of this type of 3D e-Health platform in medical schools in terms of the learning outcomes of medical students. This E-Health platform facilitated the exchange of information between doctors and patients.
Furthermore, it was easier for patients to see their medical image data, which was very helpful in understanding the status of their disease. The platform was connected with the database, which guaranteed timely access to the latest stored data. The study offers a variety of processing results and interactive modes, which enables doctors to conduct comprehensive diagnosing. Future studies will involve adding more functions like measuring, marking, and assisted diagnosing. The platform will also be tested on additional data to create a knowledge base, which could be used as a guide for diagnosis. Finally, additional commercial health applications for mobile platforms will be evaluated and studied with respect to how they can be included in different subjects of physical treatments.

Acknowledgments
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Conflicts of interest
The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

Abbreviation
2D: two dimension
3D: three dimension
CPOE: computer physician order entry system
CPU: central processing unit
CT: computed tomography
CTA: computed tomography angiography
DICOM: digital imaging and communications in medicine
E-Health: electronic health
HER: electronic health record
HIT: health information technology
HTTP: hyper text transfer protocol
ICT: information and communication technology
IP: internet protocol
JPEG: joint photographic experts group
LUT: lookup table
M-Health: mobile health
MRA: magnetic resonance angiography
MRI: magnetic resonance Image
MVC: model view controller
OpenGL ES: OpenGL for eEmbedded systems
UPHIAC: ubiquitous personal health information access
References


